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Original Communications

CANCER OF THE THORACIC ESOPHAGUS AND THE UPPER END OF THE STOMACH

A REVIEW OF TWENTY-THREE CASES THAT HAVE UNDERGONE SURGICAL EXPLORATION

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ONE year ago at the meeting of this Association, Dr. Carl Eggers[1] concluded his discussion of the papers dealing with carcinoma of the esophagus with this statement, "Members of our Association should be urged to report all their cases operated upon, in order to stimulate interest in the subject."

I, therefore, should hardly need any other excuse for reporting to you our experiences and results in twenty-three cases which have undergone surgical exploration. Thirteen of these tumors were located in the thoracic esophagus (Group I) and ten were carcinomas involving the cardiac end of the stomach and the lower end of the esophagus (Group II). The first operation was performed in September, 1936, and the most recent operation, in May, 1941.

There were nine males and four females in the thoracic esophageal tumor group and eight males and two females in the cardioesophageal group (Table I). This gives a total of seventeen males and six females, about a ratio of three males to one female. The average age of the patients in Group I was 56.7 years. The youngest patient was 47, and the oldest, 68. In Group II the average age was 55.8 years; the youngest patient was 34, and the oldest, 68.

The duration of symptoms in Group I (thoracic esophagus) was four months or less in eleven of the thirteen (Table II). This includes the time of delay on the part of the family physician before he referred the patient for operation. The family physician was dilatory in seven

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instances; the dilatory period varied from three weeks to four months. In two patients the symptoms were of eight and twelve months' duration, respectively, before any doctor was consulted. It is of interest that our only surviving patient of this group had symptoms for one year before consulting a physician.

TABLE I

AGE, SEX, AND INCIDENCE

GROUP	MALE	FEMALE	AVER. AGE (YEARS)		
I	9	4	56.7	Youngest patient	47 years
				Oldest patient	68 years
II	8	2	55.8	Youngest patient	34 years
				Oldest patient	68 years
Total	17	6			

TABLE II

(GROUP I)
CANCER OF THE THORACIC ESOPHAGUS

NAME	NO. OF MONTHS BETWEEN ONSET OF SYMPTOMS AND FIRST VISIT TO PHYSICIAN	NO. OF MONTHS BETWEEN FIRST VISIT TO PHYSICIAN AND OPERATION	TOTAL
A. R.	No delay	4 months	4 months
G. E.	3 months	No delay	3 months
A. F.	3 months	No delay	3 months
A. T.	2 months	2 months	4 months
C. S.	2 months of obstruction. Chest pain for 8 months	3 weeks	3+ months
G. B.	1 month	2½ months	3½ months
Z. S.	1 year	1 month	13 months
P. M.	1 month	3 months	4 months
A. O.	3 months	No delay	3 months
G. S.	2 months	No delay	2 months
J. F.	4 months	No delay	4 months
J. R.	2 weeks	1 month	1½ months
G. K.	2 months	No delay	2 months

In Group II (cardioesophageal tumors), the duration of symptoms was somewhat longer than in Group I (Table III). Only four patients had symptoms for four months or less before seeing a physician. One patient of this group had symptoms for twenty months before exploratory operation but proved to be inoperable after such a long interval. The referring doctor was again found dilatory in seven instances. The dilatory period varied from two weeks to seventeen months. In two of the longest periods of delay the patients were given roentgen-ray treatments before surgical exploration.

The types of tumor present in Group I and Group II are listed in Table IV. It is of interest that in one of the undifferentiated tumors in Group II, diffuse intraperitoneal metastases occurred in the twenty-six days following resection of the tumor and necropsy at this time showed the liver full of metastatic carcinoma. The liver had been free of any

palpable nodules at the time of the resection of the growth twenty-six days before.

There were four cases in Group I in which no probable metastases were present. One of these patients is alive eleven months after resection of the tumor with no evidence of recurrence as yet. Two others were studied at necropsy. The fourth patient died seven days after resection; autopsy was refused, but it was believed at the time of operation that all the tumor had been removed. Another patient in Group I expired twenty-three days after a Torek resection from a bilateral chylothorax. Autopsy revealed one metastatic lymph node high in the lesser curvature and no other evidence of metastatic deposits. This case substantiates Carter's[2] contention that we should resect the lymph nodes at the cardioesophageal junction when removing the esophagus by the Torek procedure. If we include this fifth case as a truly operable one, then five of the thirteen (38.4 per cent) can be said, theoretically speaking, to have had a reasonably good life expectancy if they had been able to survive the operative procedure.

TABLE III

(GROUP II)
CANCER OF STOMACH (CARDIOESOPHAGEAL JUNCTION)

NAME	NO. OF MONTHS BETWEEN ONSET OF SYMPTOMS AND FIRST VISIT TO PHYSICIAN	NO. OF MONTHS BETWEEN FIRST VISIT TO PHYSICIAN AND OPERATION	TOTAL
W. G.	2 months	No delay	2 months
J. L.	5 months	2 months	7 months
L. P.	2 years	1½ months	25½ months
J. H.	2 months	No delay	2 months
L. H.	3 months	17 months	20 months X-ray treatments
W. B.	No delay	2½ months	2½ months
S. C.	5½ months	2 weeks	6 months
P. F.	4 months	6 months	10 months X-ray treatments
H. M.	2 months	No delay	2 months
M. M.	5 months	2 months	7 months

TABLE IV

TYPE OF TUMOR (MICROSCOPIC DIAGNOSES)

GROUP I		GROUP II	
TYPE	NO. OF CASES	TYPE	NO. OF CASES
Epidermoid	9	Adenocarcinoma	7
Adenocarcinoma	2	Undifferentiated	2
Glandular pattern	1	No specimen	1
Transitional	1		
Total	13		10

Three patients in Group II (cardioesophageal tumors) showed reasonable evidence that the tumors were still local and that their life expect-

ancy would have been good had they recovered from radical resection. If the two additional patients whose symptoms were of ten and twenty months' duration, respectively, are combined with the three just enumerated, we find five, or 50 per cent, of this group were theoretically operable cases. One of the patients in this operable group was of extreme interest in that the lower end of the esophagus was perforated during esophagoscopy. The accident was recognized because the biopsy specimen appeared grossly to be omental fat and two hours later free air was seen under the left diaphragm in the upright roentgen film of the abdomen. This patient was operated upon approximately six hours after perforation; a transthoracic approach was employed. The entire surface of the left lung was found to be studded with firm, grayish nodules which were taken to be metastatic deposits. The perforation in the esophagus could not be demonstrated, and the operation was terminated without further dissection. The patient expired eleven days later; autopsy revealed an operable tumor, and the nodules in the left lung proved to be silicotic conglomerations. The cause of death was generalized peritonitis and left empyema resulting from the perforation of the esophagus.

TABLE V

OPERATIVE PROCEDURES

Group I	
Torek resection	7
Garlock's modification	1
Resection with reanastomosis	2
Transthoracic exploration	2
Patient expired on table during Torek resection	1
Total	13
Group II	
Resection with reanastomosis transthoracic	5
Torek resection with removal of proximal half of stomach	1
Transthoracic exploration without resection	3
Gastrostomy (exploratory laparotomy)	1
Total	10

A summary of the operative procedures in Group I and Group II is given in Table V. The Torek procedure, or a modification of this operation, was carried out in eight cases. In another case the patient expired on the table. Resection, with reanastomosis of the esophagus to the stomach, was performed in two cases; in the remaining two patients exploratory thoracotomy was performed and resection was not attempted because of the fixation of the tumor to the thoracic aorta.

In Group II, resection and reanastomosis of the esophagus to the stomach was carried out in five instances. The Torek operation was done in one case in this group because it was necessary to remove the proximal one-half of the stomach and the lower third of the esophagus; reanastomosis in this instance was impossible because of the wide area of resection. In another patient exploratory laparotomy proved the lesion

to be inoperable and a gastrostomy was performed. The three remaining patients of this group were explored through a transthoracic approach, but resection was not carried out as the lesions were considered inoperable. I have already mentioned one of these patients who was explored as an emergency because of rupture of the esophagus during esophagoscopy.

TABLE VI

CAUSES OF DEATH (EARLY)

(GROUP I)

PATIENT	SHOCK, INFECTION, TRAUMA OF THORACIC DUCT, OR POSSIBLE ANESTHETIC DEATH
C. S.	Died second postoperative day. Resection not done. Tumor had extended into aorta and left main bronchus. Cause of death—shock
P. M.	Died eighth postoperative day. Abscess in posterior mediastinum. Trachea perforated during operation. Tumor tissue left along arch of aorta
A. O.	Died sixth postoperative day. Gangrene of lungs and left empyema. Tumor tissue left in mediastinal bed
J. R.	Died seventh postoperative day. Left empyema
G. K.	Died four days postoperative. Left empyema, bilateral bronchial pneumonia
G. E.	Died on table. Inoperable case. Resection should not have been attempted
G. T.	Died on twenty-third postoperative day. Bilateral chylothorax. One metastatic node high on lesser curvature. No other metastases
J. F.	Died second postoperative day. Remained stuporous after operation. Anastomosis tight. Possible anesthetic death.
	Conclusion: There were eight deaths in this group. Four of these cases were truly inoperable

TABLE VII

LATER CAUSES OF DEATH

(GROUP I)

PATIENT	INFECTION AND METASTASES
G. B.	Died three months after operation. Left empyema. Tumor tissue left along the arch of the aorta
G. S.	Died two and one-half months after operation. Metastases involving chiefly the sensory roots of the dorsal and lumbar nerves
A. R.	Died ten and one-half months after operation. Diffuse intraperitoneal metastases
A. F.	Died two and one-half months after exploratory thoracotomy. Perforation of the carcinoma into the thoracic aorta (was receiving x-ray treatment)
	Conclusion: These patients all died from persistence or recurrence of their tumor
	Late Survivor and General Conclusion
Z. S.	Alive and well eleven months after Torek resection. No metastases were present in the lymph nodes removed with the surgical specimen
	Conclusion: Of the eight patients who met early deaths, four would have had a reasonably good outlook if they had survived the operation. This number is the group I should like to consider as the operative mortality, approximately 30+%

There are only three patients of this entire group alive today.* Two of these are inoperable and their days are numbered. Only one has a good prognosis. This patient is alive eleven months after a Torek re-

*See addendum.

TABLE VIII

CAUSES OF DEATH

(GROUP II)

PATIENT	
W. G.	Died 36 hours postoperatively. Bilateral tension pneumothorax due probably to injury to left main bronchus in freeing the thoracic esophagus
B. W.	Expired 24 hours after operation. Left empyema. Tumor tissue left retroperitoneally
P. F.	Died fifth postoperative day. Tumor tissue left retroperitoneally
J. L.	Expired upon completion of the operation. Torek procedure necessary because of the extent of involvement
H. M.	Expired twenty-sixth postoperative day. Diffuse intraperitoneal metastases, not present at the time of the original resection
J. H.	Expired eleventh postoperative day after exploratory thoracotomy. Generalized peritonitis and left pleural empyema. Mistake as to metastatic spread
L. H.	Died one and one-half months after exploratory thoracotomy. Inoperable tumor
L. P.	Died sixteen months after resection and reanastomosis. Died of recurrence
	There are two patients still alive
C. S.	Exploratory thoracotomy four months ago. Liver metastasis at this time. Resection not done. Patient is rapidly failing
M. M.	Gastrostomy one month ago. Tumor extending into the pancreas. Considered inoperable. Severe abdominal wall infection following gastrostomy
	Conclusions: There have been eight deaths in this group. Three of these patients had a reasonably good outlook if they had survived the operative procedure. As in Group I, I should like to consider these three patients as representing the operative mortality which would be 30%

TABLE IX

ACTUAL MORTALITY RATE OF RESECTION

Group I

Resection carried out in	10	Survived resection
Exploratory operation	2	2 months or longer
Patient expired on table	1	4
	—	Expired within 1 month
Total	13	after operation
		6
Mortality rate of resection		60%
Garlock's rate of resection		38%

Group II

Resection carried out in	6	Survived resection
Exploratory operation in	4	2 months or longer
	—	1
Total	10	Expired within 1 month
		after operation
		5
Mortality rate of resection		83+%
Garlock's rate of resection		40%

section, and the lymph glands removed with the tumor were free of metastases. I have grouped the causes of death into early and, perhaps I had best say, later causes since the longest survival period has been sixteen months (Tables VI, VII, and VIII).

It will be noted in Tables VII and VIII that I have calculated the operative mortality in Groups I and II for those patients possessing truly operable lesions. The particular reason for doing so was to demonstrate the direct relationship between the extent of the pathology and the mortality rate of operative removal of the lesion. The more advanced the tumor, the higher the mortality rate of resection. It has been our experience in the cardioesophageal tumors that often the inoperability of the lesion becomes apparent only after the stomach has been divided distally and then we encounter cancerous fixation to the pancreas or extension into the retroperitoneal lymphatics.

The actual mortality rate of surgical excision of the tumor is seen in Table IX. The rates are very high in both groups, particularly when compared with the splendid accomplishments of Garlock.[1]

There are certain clinical points that of necessity come up for discussion since we are dealing with procedures that have only in recent years given evidence of promise.

We prefer to introduce a pneumothorax in the left pleural cavity several days before resection. The left lung is collapsed as much as possible without increasing the intrapleural pressure above a positive 2 cm. of water.

Cyclopropane, delivered through an intratracheal catheter, is our choice for anesthesia. We realize that a skilled, well-trained anesthetist is the only one qualified to control the many factors involved in intratracheal anesthesia. On the other hand, we believe that the major portion of the credit for advance in thoracic surgery is due the anesthetist rather than any particular skill of the surgeon. It is our firm belief that, if we are to advance in problems as difficult as the subject under discussion, we must have trained doctors delivering the anesthetic gas.

Garlock,[3] in a recent communication, has advised the use of the lower end of the esophagus as a permanent esophagostomy to replace the gastrostomy as is generally employed in the Torek operation. Our experience agrees with Garlock's contention that all types of gastrostomies leak to some extent. We followed Garlock's suggestion in one case and brought out the lower end of the esophagus on to the abdominal wall as a permanent esophagostomy. It is my feeling, however, that this procedure adds too much to an already long and difficult operation and I am approaching the gastrostomy problem in a different manner. Figs. 1, 2, 3, and 4 adequately explain what I have in mind. I have not employed this technique upon the human patient as yet since the experimental work on dogs has not been completed. The type of gastrostomy demonstrated here, does not leak (in the dog), and I believe it will

render the use of the rubber tube for feeding purposes less irksome. Furthermore, when an antethoracic esophagoplasty is to be fashioned, I believe this type of gastrostomy will be more readily applicable, since we shall be sewing skin to skin rather than skin to gastric mucosa.

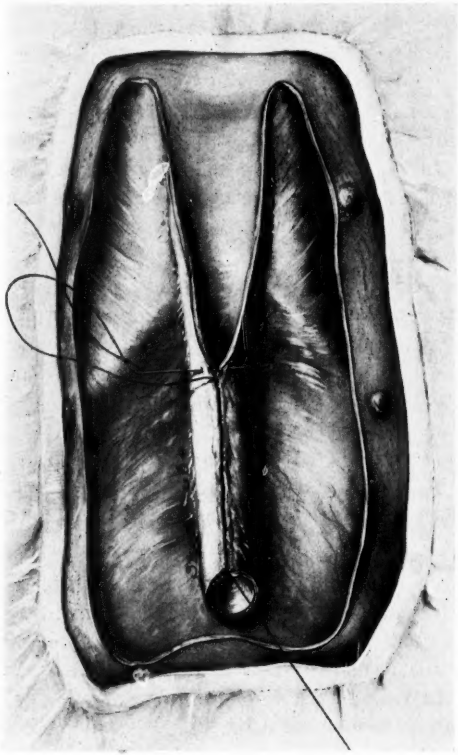

Fig. 1.—A skin tube is fashioned from the anterior wall of the lower thorax and upper abdomen. The distal half of the skin tube is raised from the anterior abdominal wall.

Bird,[4] in 1939, when speaking about the precautions in esophagectomy, mentioned the fact that no injuries to the thoracic duct during esophagectomy had been recorded thus far. He also stated that, because of the numerous anastomoses of the thoracic duct with other lymphatic ducts and with veins, ligation of the main channel, though obviously unadvisable, usually does not lead to serious consequences. He concluded that division of the main thoracic duct without ligating it no doubt would be disastrous. This very complication led to the death of one of the patients in Group I on Nov. 16, 1939. Death resulted from recurring and persistent bilateral chylothorax. Since this complication it has been our practice to mobilize the aortic arch in those lesions lying behind this structure. This maneuver is accomplished by division of the parietal

pleura lying on either side of the aortic arch. A hernia tape is placed around the arch and by the use of gentle traction the intercostal arteries are demonstrated as they leave either side of the posterior surface of the

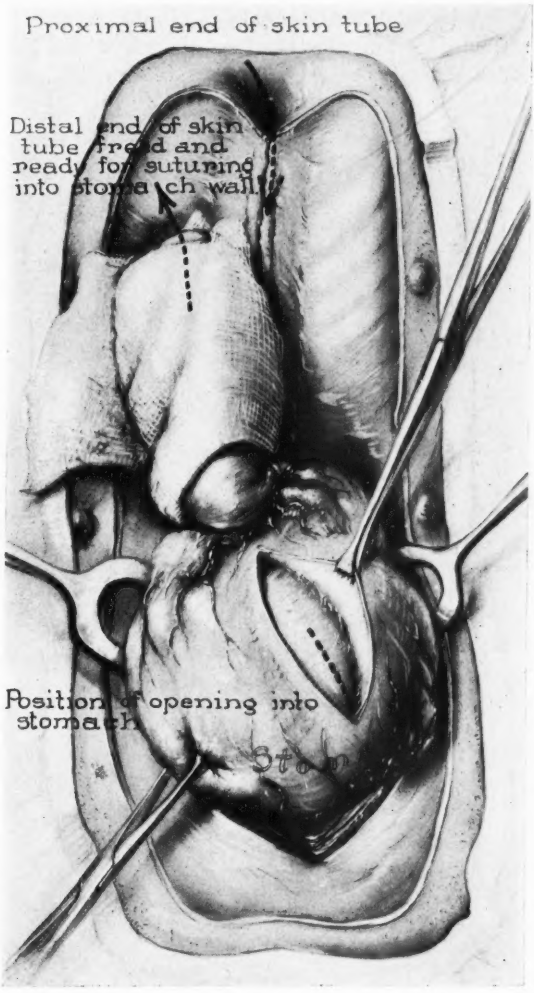
Proximal end of skin tube
Distal end of skin tube freed and ready for suturing into stomach wall
Position of opening into stomach

Fig. 2.—A serosal flap is raised from the anterior wall of the stomach. The free distal half of the skin tube will be buried in this portion of the stomach.

thoracic aorta. Upon occasion we have divided three or four pairs of the intercostal arteries extending from the arch downward toward the diaphragm. These vessels are tied on the aorta side and occluded with silver brain clips on the rib side. Following the division of these intercostal vessels the aortic arch can be retracted forward and to the right.

An excellent view of that portion of the esophagus lying behind the arch is now obtained (Fig. 5). Since adopting this technique, we believe we have seen the thoracic duct several times and, if necessary, have divided it between ligatures. I have had in mind administering a fat staining dye by mouth preliminary to esophagectomy, hoping such a dye might better demonstrate the thoracic duct at the time of operation. This idea has not been carried out as yet in actual practice.

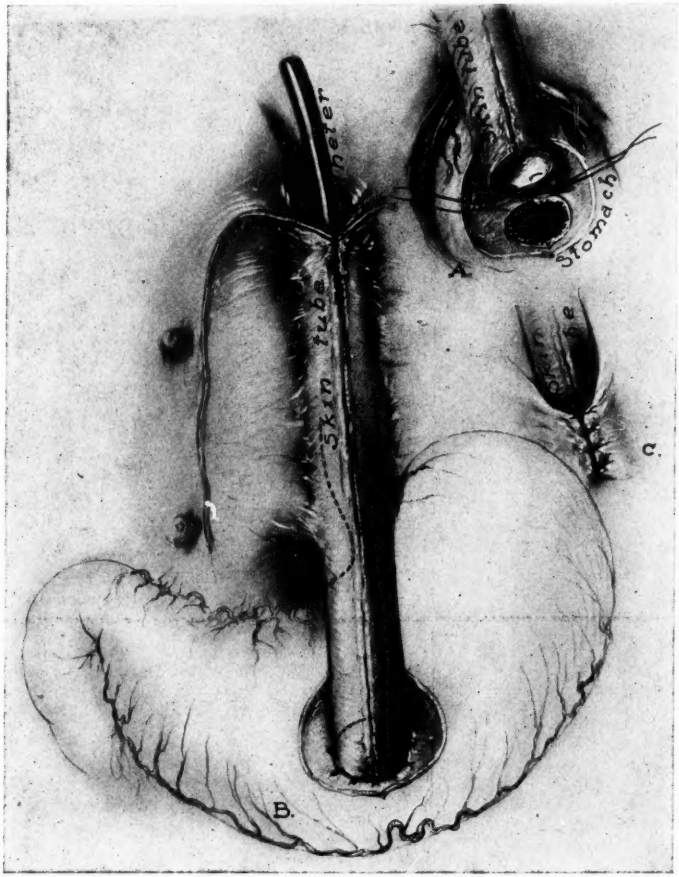

Fig. 3.—The skin tube is anastomosed to the anterior wall of the stomach, near the greater curvature. The upper insert shows the beginning of the anastomosis. The lower insert demonstrates the completed anastomosis; the serosal flap has been reapproximated to cover the site of anastomosis.

We have followed the recommendations of Garlock[5] both in the methods of incision and approach for the types of lesions under discussion. We have had no experience with the approach through the right thorax for mid-esophageal lesions as recommended by Ochsner

and DeBakey.[6] The crossing of the esophagus to the left of the midline at its lower end, the small size of the left lobe of the liver in comparison with the right, and the exposure of the arch of the aorta from the left side, I believe, are significant reasons for favoring the left-sided approach. It is my opinion that Garlock's emphasis of the necessity to carry the division of the ribs in the paravertebral line up to and including the fourth rib in the removal of mid-esophageal lesions is particularly well taken. Such an incision provides excellent exposure of the esophagus above the arch of the aorta; the esophagus can be freed up to the root of the neck, rendering the second step of the Torek operation a relatively quick and simple procedure.

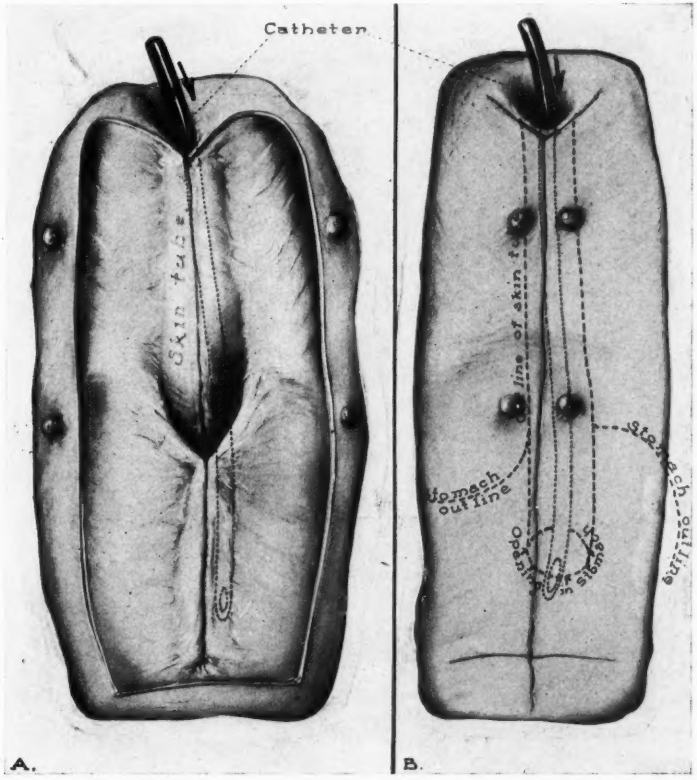

Fig. 4.—The undercut skin layers on either side of the skin tube are approximated over the skin tube to complete the procedure.

It has been our practice to explore all those lesions involving the cardioesophageal area through the transthoracic approach if it is at all feasible. In only one of the ten cases in Group II was the abdominal approach employed. In this instance the patient was 68 years old and

was markedly dehydrated; it was very questionable whether she had an operable tumor. Dehydration can be handled, as a rule, by passing a nasal tube into the stomach, and by the use of the nasal tube the patient's water and nutritional balance can be re-established. It is our opinion that a very adequate exposure of the upper abdominal contents is obtained through the transthoracic approach and we prefer to carry out the resection and reanastomosis in a one-stage procedure. We have not performed a gastrostomy preliminary to resection in this group. The main reason for this line of procedure has been the fact that we have needed all the stomach available to obtain sufficient relaxation to re-establish esophageal gastric continuity. A preliminary gastrostomy in such instances would certainly have interfered with the complete mobilization of the stomach.

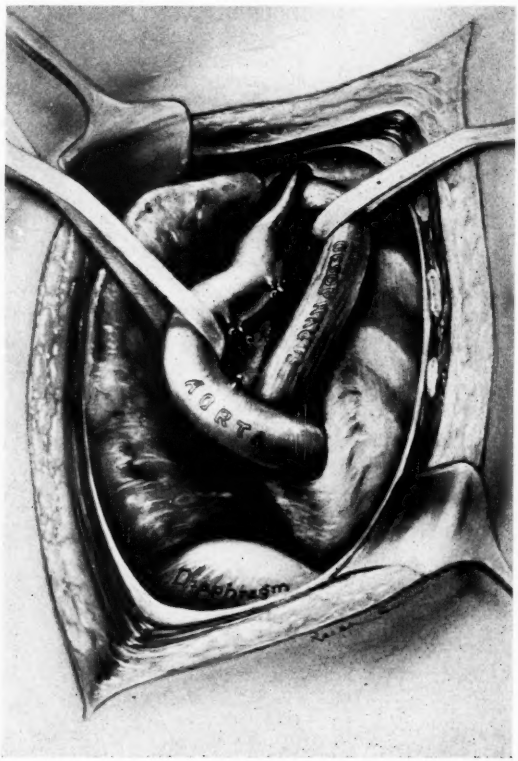

Fig. 5.—The aortic arch has been drawn forward and to the right following the division of several intercostal arteries. The excellent exposure of that portion of the esophagus lying behind the arch is well demonstrated.

Experimental work on the dog begun by Adams[7] and recently confirmed and elaborated by Carter and his co-workers[8] seems to show rather conclusively that, in the reanastomosis of the stomach to the esophagus, a two-layered union employing interrupted sutures will pre-

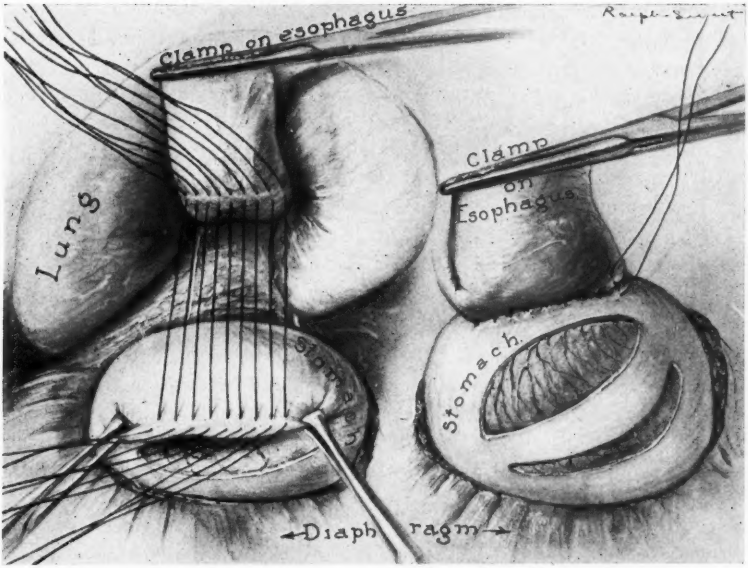

Fig. 6.—The stomach is anchored high on the posterior wall of the esophagus. A flap of serosa has been raised from the anterior wall of the stomach; the distal end of the esophagus will be drawn under this flap; the esophagogastrostomy will be accomplished; and finally the serosal flap will be sewn down to cover the line of anastomosis.

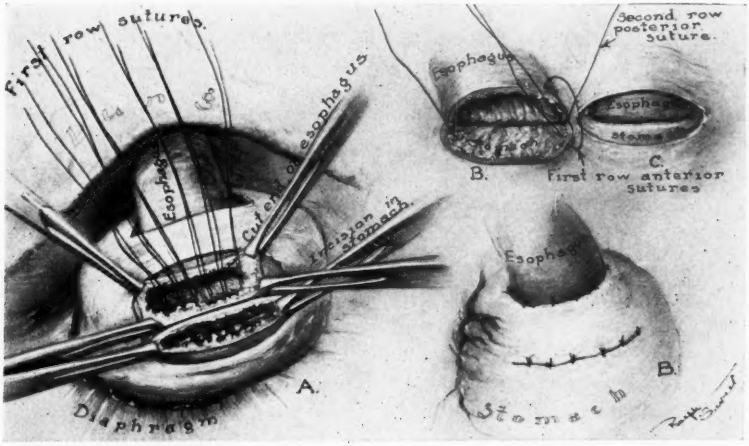

Fig. 7.—The anastomosis is carried out with interrupted silk sutures. The lower right-hand drawing shows the completed anastomosis covered by the flap of serosa.

vent stenosis at the cardioesophageal junction. I prefer the use of silk sutures for this anastomosis, but Carter and his co-workers stated that catgut or silk for the inner row of sutures gives no noticeable differences in operative results (on the dog). Adams deserves considerable credit for demonstrating and emphasizing the importance of anchoring the stomach high to the posterior wall of the esophagus above the expected line of anastomosis. This maneuver takes the tension off the actual anastomotic suture line. Carter and his workers agree with Adams' contention that an end-to-side union between the esophagus and the stomach is the best method for uniting these two structures. The Cincinnati group have elaborated upon Adams' work and recommend anchoring the esophagus and the stomach on either side of the suture line to the intervertebral discs medially and the periosteum of the ribs laterally. These sutures are placed so that the intervening esophagogastrostomy is freely movable and not under tension. We have followed the basic principles laid down by Adams for cardioesophageal union and, in addition, when sufficient stomach is present, have turned up a serosal flap from the anterior gastric wall and sewn this flap down over the anastomotic line. When such a maneuver is possible a very snug closure of the suture line results (Figs. 6 and 7).

It has been our practice to drain the pleural cavity in all cases where cardioesophageal resection has been performed. We do not drain the pleural cavity in the Torek procedure unless gross contamination has complicated this type of resection. The experience of Blades[9] in the use of the sulfonamide group of drugs points to the use of these agents as a valuable means to lessen the virulency of a complicating postoperative empyema. Recently we have scattered sulfanilamide powder, 4 to 6 Gm., about the anastomotic site before closing the thoracic cage. We are in no position to evaluate the efficacy of this therapy.

CONCLUSIONS

A review of our experiences in twenty-three cases of carcinoma has been presented. Thirteen of the tumors were located in the thoracic esophagus, and ten involved the cardioesophageal junction. One of the patients had previously been reported as representing a successful resection of a carcinoma of the thoracic esophagus. Four additional patients who survived resection of their tumor are reported in this communication, but three of the four are dead from recurrence or spread of the original growth. Only one patient who has undergone resection of the carcinoma is alive and well today.* This patient, we believe, has a good life expectancy.

A general discussion of the significant points covering the clinical management of tumors in this location has been presented along with some of our own methods of practice.

*See addendum.

We have followed the advice of a pioneer in this branch of surgery, namely, Dr. Carl Eggers, and reported our experiences to date. We still possess the optimism of Dr. Eggers, believe we can do better in this difficult field, and agree with him that the best method to accomplish this goal is to continue active discussion of the problem.

ADDENDUM

There is only one patient alive (May, 1942) of this entire group of twenty-three cases. It is now twenty-two months since the original esophageal resection in our only survivor. This particular patient is now in good physical condition and will shortly have her anterior skin tube united to the stomach by the Wullstein-Roux operation. There is no evidence of recurrence in this patient.

There have been four additional successful resections since this paper was presented, three cardio-esophageal resections with reanastomosis and one Torek resection. In one patient of this latter group it was necessary to remove the entire stomach and the spleen. The esophagus was united to the jejunum by an end-to-side anastomosis and an enteroanastomosis between the two loops of jejunum below the transverse mesocolon. This entire procedure was carried out through a transthoracic approach.

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(See discussion on page 509.)

EXPERIENCES WITH EIGHT CASES OF RESECTION OF THE ESOPHAGUS FOR CARCINOMA

DALLAS B. PHEMISTER, M.D. (BY INVITATION)
CHICAGO, ILL.

AT THE 1938 meeting of the American Association for Thoracic Surgery, Dr. William E. Adams reported the case of a 53-year-old woman who had carcinoma of the terminal esophagus which he and I had treated by transthoracic resection and esophagogastrostomy. She was then alive and free from signs of recurrence three months after operation. Since then there have been seven other cases on my service—all in males—in which the esophagus has been resected for carcinoma. The tumor was primary in the esophagus in six of the eight cases and secondary by extension from the cardiac end of the stomach in two. In most of the cases Dr. Adams and I have worked together, and in one case of tumor located at the level of the tracheal bifurcation I assisted the resident surgeon, Dr. John Prohaska, in a successful resection.

The patients have ranged in age from 46 to 64 years. The site of involvement in the six primary esophageal cases was at the following levels from above downward: the arch of the aorta in one, near the tracheal bifurcation in three, the junction of the middle and lower thirds in one, and the terminal portion in one. Of the six patients, four survived the operation or operations, giving a mortality of 33⅓ per cent. Of the two with primary gastric cases, one survived. Of the total of eight patients, five survived, giving a mortality of 37.5 per cent.

Resection and esophagogastrostomy was performed in four cases—the lowest two primary in the esophagus and the two primary in the stomach. One of each group survived the operation. Resection and cervical esophagostomy was performed in case of the upper four tumors with three survivals. Three of these patients had gastrostomies, one before and two at the time of the resection. One case, in which the tumor was at the level of the arch of the aorta, had an inferior or abdominal esophagostomy performed during the thoracic operation according to the method of Garlock.

The most important factor in the causation of death in the three cases was soiling with infection of the pleura and, in one case, leakage of the anastomosis.

METHOD OF PROCEDURE

A preliminary blood transfusion was given to all patients with any considerable degree of anemia or debility.

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Both the left chest and the abdomen were prepared for operation, and an ankle vein was prepared for intravenous injection.

The chest was opened through the eighth rib bed in the two cases of primary carcinoma of the esophagus treated by resection and esophagogastrostomy. For the four tumors situated higher up, the approach was through the seventh rib bed or interspace with division of the fifth and sixth ribs posteriorly. In the cases of primary gastric carcinoma, the resection was made through the ninth rib bed. While it gave a good exposure at the level of the stomach, the anterior limit of the incision was somewhat too far lateral for convenience of work especially in ligating of the lower curvature. If a low exposure is needed for the gastric cases, it might be better obtained through the eighth rib bed or by dividing the eighth or eighth and ninth ribs posteriorly after resection of the seventh rib.

Ethylene-oxygen-mask anesthesia was used, and a positive pressure of 5 to 6 mm. mercury was maintained during the period that the chest was open.

Blood transfusion was given in every case and was started at some time during the intrathoracic procedure. From 500 to 1,100 c.c. were administered. Blood transfusion is an important factor in maintaining the circulation and respiration. In difficult and unfavorable situations, it enables the surgeon to operate with greater speed and, if necessary, with more than the usual blood loss without producing shock since a transfusion capable of preventing it may be given simultaneously. The operations have lasted from two and three-fourths to four and three-fourths hours, and the chest has been open for over three hours in some cases. The saving of time may become a factor of importance, and under such circumstances the surgeon should not make a fetish of meticulous hemostasis at the risk of prolonging the operation unduly and embarrassing the circulation and respiration.

In the lower esophageal and gastric cases where esophagus and stomach were anastomosed the left diaphragm was paralyzed by pinching the phrenic nerve. This procedure facilitates resection and subsequent operative repair and healing of the diaphragm. After the lower lobe of lung was detached and retracted, the mediastinal pleura was incised and the lower esophagus was isolated, including the accompanying vagi which were excised along with it in all cases. Upward retraction of the lung is facilitated by a malleable retractor cut to fit a cross section of the lower part of the left side of the chest (Fig. 1). The diaphragm was then opened for about 4 inches in a posteromesial direction back to the aperture and separated from the esophagus. In our first case, which Dr. Adams presented previously, the tumor extended down to the stomach and the lymph nodes high on the lesser curvature were involved. The upper part of the greater curva-

ture was liberated, and the lesser curvature beyond the limits of the lymph nodes was freed down to the gastric artery, which was divided and ligated allowing elevation of the stomach. The stomach was then transected between two clamps about 2 inches from the cardia, and the distal end was closed. The fundus was anastomosed to the end of the esophagus with two rows of interrupted linen sutures, an inner through-and-through and an outer Lembert. There was no tension on the suture line. A catheter gastrostomy was then done. This procedure has since been discontinued. The diaphragm was closed about the stomach and sutured to its wall. The chest was closed with an intercostal catheter for suction drainage.

Fig. 1.—Malleable retractor for upward retraction of lung during lower thoracic and gastric resections.

This patient made an uneventful recovery and is now alive* without evidence of recurrence three years and four months after operation. No case has been found on record with as long a survival period after resection and esophagogastrostomy as this one. She leads an active life but is troubled some at night or in the early morning with nausea and vomiting of small amounts of a mucous fluid. On fluoroscopic, barium meal examination, the esophagogastric stoma is large and the stomach fills readily. Most of the stomach is within the chest and there is a tam-o-shanter-like pouch of the fundus extending downward to the left of the anastomosis. No peristalsis can be seen in the body of the stomach as would be expected in view of the fact that the vagi were resected along with the involved esophagus. However the stomach empties more rapidly than normal aside from the pouch whose emptying time is somewhat delayed. The pylorus is open, and very active peristaltic

*Four years and three months (May, 1942).

waves starting in the antrum and proceeding distally carry the barium rapidly into the duodenum and jejunum. The nausea and vomiting are not easy to explain. If retention in the fundus pouch were the cause, the vomitus might be expected to contain food, but this is rarely the case. Reflux of duodenal juices into the paralytic stomach above the diaphragm during the sleeping hours and incontinence of the gastroesophageal stoma appear to be the factors of most importance.

In the other case of low involvement of the esophagus, the long tumor ended about 2 inches above the diaphragm, and, when the diaphragm was incised, the lesser curvature lymph nodes contained metastases. After the curvatures of the stomach were freed as in the other case and the metastases were excised, the esophagus was divided above the cardia and its stump was invaginated. The spleen had to be mobilized and brought up with the stomach and the fifth, sixth, and seventh ribs were divided posteriorly in order to be able to make the anastomosis of stomach and esophagus which was about the level of the tracheal bifurcation. In this and subsequent cases, umbilical tape was tied about the esophagus to prevent leakage during the anastomosis. A clamp was placed on the stomach. The stomach was also anchored to pleura alongside the esophagus to take the tension off the anastomosis. The diaphragm was closed about the stomach, leaving the spleen in the chest.

In this case too much collapse of the lungs was permitted, and insufficient blood transfusion was given so that during the performance of the anastomosis the heart stopped beating. It responded to an intracardiac adrenalin injection, and with further blood transfusion the patient rallied completely from the shock. Three days later death was caused by left-sided pleural infection and an early pneumonia. At autopsy the anastomosis between esophagus and stomach was found to be intact.

In the two cases of gastric carcinomas with obstruction of the terminal esophagus, the operative procedures were similar to that in the first case except that the stomach had to be freed lower along the greater curvature and the spleen was removed, a procedure now recommended in all cases of esophagogastrostomy.

The first case was that of a 46-year-old male who had distress after eating and gradually increasing difficulty in swallowing over a period of fifteen months with a loss in weight of 25 pounds. The history and physical findings were otherwise without special significance. Roentgenologic examination revealed a filling defect in the cardiac end of the stomach and narrowing of the terminal esophagus (Fig. 2). At operation the stomach was explored through a midepigastric incision, and the tumor was judged to be resectable. After the left chest and diaphragm were opened, the tumor was found to be adherent to the posterior wall high on the lesser peritoneal cavity. The greater curvature was freed down to the spleen, which was removed. The adherent

Fig. 2.—Carcinoma of cardiac end of stomach with obstruction of terminal esophagus.

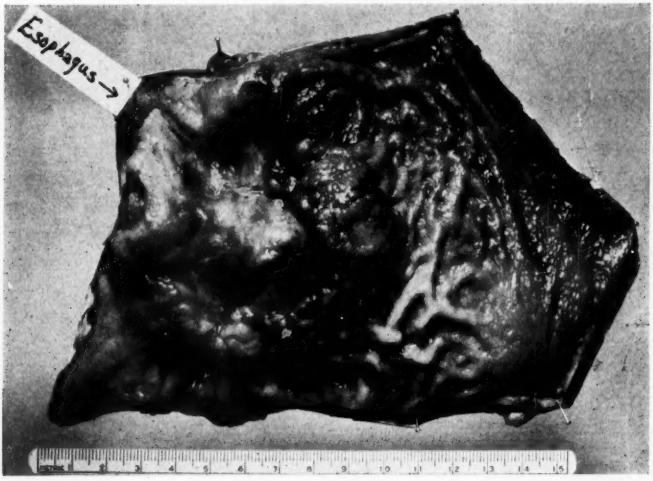

Fig. 3.—Specimen resected from case shown in Fig. 2.

posterior peritoneum was then dissected off with the tumor; the lesser curvature was freed; and the gastric artery was divided and ligated. About two-thirds of the stomach was removed, and the end of the esophagus was easily anastomosed to the anterior wall of the remaining portion of stomach within the chest by the technique used in the previous cases. Fig. 3 shows the resected specimen. About one-half of the remaining portion of stomach was in the chest after closure of the diaphragm. The patient made an uneventful recovery from the operation. Mouth feeding was resumed on the sixth day. Three and one-fourth months have now elapsed, and the patient has gained very slowly in weight and strength. He experiences no difficulty in swallowing but must eat slowly and can tolerate only liquid and semisolid diets. Meats and vegetables produce attacks of nausea and vomiting.

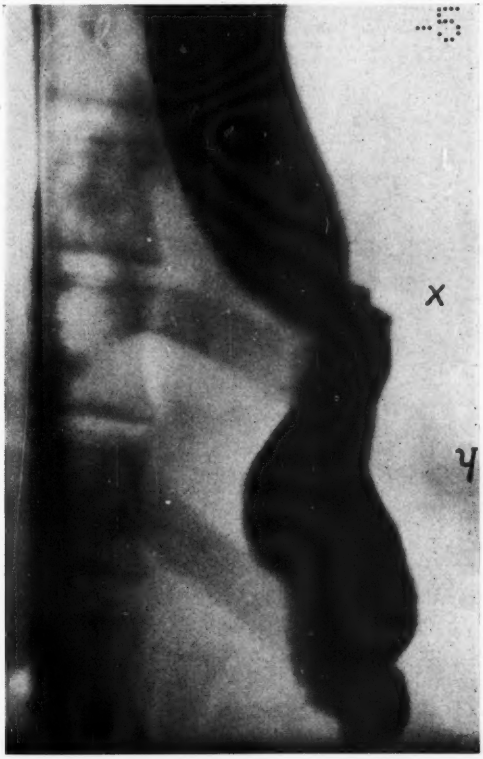

Fig. 4.—Roentgenogram of case shown in Fig. 2. Two and one-half months after resection and esophagogastrostomy. *X* is the level of the anastomosis; and *y*, the level of the diaphragm.

He also is subject to vomiting of small amounts of liquids day or night as a result of lying down for some time. A roentgenologic examination two and one-half months after operation showed barium passing freely through the anastomosis and the small remaining portion of

stomach although no peristalsis was seen in the stomach. Fig. 4 shows the anastomosis and what is left of the stomach. The stomach emptied readily during the examination. The nausea and vomiting appear to be due to the incontinence of the esophagogastric stoma and to the stomach which is atonic due to vagal nerve section and which fails to carry solid foods.*

The second stomach case was that of a 62-year-old male who had had stomach distress and loss of weight for nine months and increasing difficulty in swallowing for four months. Physical examination revealed no findings of special interest aside from moderate anemia and weight loss. A roentgenologic examination showed a definite narrowing and retardation of barium in the terminal portion of the esophagus. There was a large filling defect with cauliflower-like edges on the posterior wall of the cardiac end of the stomach.

Fig. 5.—Malleable retractors for retracting anterior resection of lung during upper thoracic esophageal resections.

The patient was operated on in a manner similar to that of the first case, and the pathologic findings were similar. About three-fourths of the stomach was resected. However, when the anastomosis was made, the clamp was left off the stomach because of interference with approximation of stomach and esophagus. As a result there was some soiling of the field from leakage of gastric contents. The patient lived for eight days. At autopsy leakage of the anastomosis and a large localized abscess were found. They appeared to have resulted from infection following the soiling.

Little time will be devoted to a discussion of the three cases in which the carcinoma of the esophagus was located near the level of the

*In May, 1942, fifteen months after operation, the patient was free from signs of recurrence and relatively free from gastric symptoms.

tracheal bifurcation. They were operated on by the technique of Torek, dividing the esophagus in the chest and bringing the proximal tumor-bearing end out through the neck. Anterior retraction of the lung in these cases is facilitated by the use of a large headed malleable retractor (Fig. 5). In one case where a preliminary gastrostomy had been performed and metastases were discovered in the lymph nodes high on the lesser curvature, the diaphragm was opened during the thoracic operation and the metastases were removed. One patient died seven days after operation from infection of the right pleura and mediastinum. One lived for ten months, and one, for fourteen months; both patients died from continued growth of tumor within the chest.

The case in which the tumor was located at the level of the aortic arch is of special interest. A 48-year-old male had had progressive difficulty in swallowing and weight loss for six months. Roentgenologically there was marked narrowing at the tumor site, and at operation the tumor was extensively fixed to adjacent structures. Separation of the involved segment of esophagus was made with great difficulty, and the left recurrent laryngeal nerve was divided, leaving the patient with paralysis of the left vocal cord. Other fibers of the vagi going to the heart and lungs were also divided, but there were no untoward results from their division. This procedure, however, should be carried out with caution. While excision of the vagi along the esophagus below the origin of the branches to the heart and lungs may be done with safety, the division of the vagi about the aortic arch or of their fibers to the heart and lungs during the removal of a tumor located high in the esophagus might predispose to pneumonia and death, as is the case when the vagi are divided in the neck in experimental animals.

In this patient the esophagus was freed down to and from the diaphragm and divided 3 inches above the lower end. The distal end was infolded with two purse-string sutures, and an inferior esophagostomy was performed after the manner of Garlock. A small incision was made through the abdominal wall just below and to the left of the xiphoid, and a long hemostat was passed backward beneath the left lobe of the liver and diaphragm and emerging through the aperture of the diaphragm. The purse-string suture was then grasped, and the stump of esophagus was pulled through and anchored to the skin. The superior esophagostomy was performed in the lower part of the neck. The patient is now alive and questionably free from mediastinal recurrence six months after operation. There has been no leakage of gastric juice from the inferior esophageal stoma. The mushroom end of a large catheter serving as an artificial esophagus recently eroded the upper esophageal stoma and produced a stenosis which has temporarily interfered with use of an artificial esophagus.*

*In May, 1942, seventeen months after operation, he was still free from signs of recurrence.

It is recommended that preliminary gastrostomy be done away with in practically all cases that are explored with the intention of resecting the esophagus. In the case of the low esophageal tumors, a preliminary gastrostomy interferes with the performance of an esophagogastrostomy. With the high esophageal tumors it should usually be possible to perform an inferior esophagostomy which does not leak as does a gastrostomy and which should work well in the construction of a skin tube esophagus. When it is found impossible to perform an inferior esophagostomy, a large mushroom catheter gastrostomy may be quickly done between the thoracic and the cervical stages of the operation.

Postoperatively all patients are either put in an oxygen tent or given oxygen through an intranasal catheter.

With the rapid strides that are now being made in numerous clinics, esophageal resection for carcinoma of the esophagus or of the cardiac end of the stomach should soon become a generally established procedure. Every such case should be regarded primarily as a surgical one. In general, it should be possible to diagnose carcinoma of the esophagus earlier than carcinoma of the stomach because of its relatively early obstructive symptoms and positive x-ray findings and because of the possibility of examination with the esophagoscope and biopsy. With early recognition and early operation, the immediate and late results of resection in carcinoma of the esophagus should soon approach those obtained at present in carcinoma of the stomach, and the results in carcinoma of the stomach should be enhanced because carcinoma of the cardiac region has become a resectable lesion.

SUMMARY

Resection of the esophagus has been performed eight times for carcinoma which was primary in six cases in the esophagus and in two cases in the cardiac end of the stomach with extension to terminal esophagus.*

Four of the six primary esophageal cases survived the operation. One patient with an esophagogastrostomy is alive and free from recurrence three and one-third years after operation, and one patient with cervical and abdominal esophagostomies is alive and questionably free from recurrence six months after operation. One patient lived for ten months, and another lived for fourteen months before dying of recurrences. One of the two patients with secondary esophageal involvement from gastric carcinoma survived the operation of resection and esophagogastrostomy and is free from signs of recurrence three and one-half months later. The principal cause of death in the three fatal cases was infection of the mediastinum and pleura.

The two surviving patients following resection and esophagogastrostomy show absence of peristalsis in the remaining portions of the

*On May 5, 1942, there were twelve cases with eight immediate survivals.

stomach on fluoroscopic examination and are subject to attacks of nausea and vomiting of small amounts on lying down for some time. The principal causes appear to be incontinence of the esophagogastric stoma and paralysis of the body of the stomach from resection of the vagi.

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(See discussion on page 509.)

AN EXPERIMENTAL STUDY OF TUBES MADE FROM THE GREATER CURVATURE OF THE STOMACH

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THE real need for a satisfactory method of reconstructing the esophagus has prompted the studies reported in this paper. One has only to read the literature on esophagoplasty to realize that the successful plastic reconstruction of the gullet is a rare surgical feat and one which usually requires many operations extending over a period of months or years. The methods which have been advocated for the formation of a new esophagus have been four, viz., by (1) a tube of skin, (2) a portion of intestine with or without the addition of a skin tube, (3) a tube fashioned from the stomach with or without the addition of a skin tube, and (4) a considerable portion of the intact stomach placed beneath the skin of the chest wall. A detailed description of these methods with a review of the literature was published by Ochsner and Owen in 1934.[1]

In our experiments we have used only a tube constructed from the greater curvature of the stomach. Such a tube appeals to us for the following reasons: (1) It is lined with mucosa; (2) tubes of considerable length (from 15 to 30 cm.) may thus be formed; and (3) the blood supply to such a tube is excellent (the left or right gastroepiploic artery), and in man the blood vessels actually run in the wall of the tube. The natural vascularity of the tube makes it unnecessary to transfer mesentery with the tube as must be done with a tube formed from the intestine. The mesentery of the intestine also limits the length of the tube and makes a considerable mass of tissue with which to deal.

We have constructed a tube from the greater curvature of the stomach at one operation, its lumen remaining in continuity with that of the stomach at both ends. In this way, at a subsequent stage, one can be assured of a long well-healed tube with an adequate blood supply which can be used either within the thorax or beneath the skin without fear of leakage.

In thirty-one dogs such tubes have been formed. Four of these tubes showed evidence of leakage varying from minute amounts to a frank

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rupture; all of these occurred in the early stages of the work, before certain technical faults were corrected. After this stage was passed, all of the tubes were satisfactory. None of the animals showed disturbance of gastric function after the tube had been made and all ate well without vomiting or loss of weight.

The tubes formed from the greater curvature may have their base at the cardiac end or at the pyloric end of the stomach. The former method was described by Beck and Carrell[2] and later by Jianu;[3] the latter method was advocated by Rutkowski.[4] We have utilized the Beck type of tube in one series of eleven dogs in which the tube at the second stage of the operation was placed partly in the thorax and partly on the chest wall. There was no leakage from the tubes, and they healed satisfactorily in all cases.

In another series of ten dogs we have used the Rutkowski type of tube and brought it up beneath the skin of the chest wall. All these tubes remained healed and proved to be satisfactory from the anatomic standpoint. The Beck tube is obviously antiperistaltic, and its open end is from the pyloric end of the stomach where low acidity exists. The Rutkowski tube is isoperistaltic, and its open end is from the cardiac end of the stomach where high acidity exists. Consequently, there should be less leakage but more acid secretion from the latter type of tube. X-ray and fluoroscopic studies were made on four dogs from one to three months after tubes had been placed either within the thorax or beneath the skin. No peristalsis was seen in any tube.

In the majority of our animals in which the Beck type of tube was brought up through the thorax we had difficulty with excoriation of the skin around the edge of the gastric tubes. There were always leakage of gastric juice, often in spurts, and at times leakage of stomach contents with consequent digestion of the skin, and finally leakage into the deeper tissues in the vicinity of the stoma. This leakage was felt to be due in part to the fact that, in the dog, the stoma is on a level with or lower than the stomach and gastric contents can easily spill from it, and in greater part to the fact that the tube pursues a straight course from the stomach to the stoma so that there is no valve-like action to prevent regurgitation. In the Rutkowski type of tube brought up beneath the skin there was much less leakage of gastric juice and never any spilling of stomach contents. The best explanation of this was that there was definite kinking of the tube where it crossed the costal margin, and this prevented regurgitation. This excoriation of the skin was our major difficulty throughout the experiments on dogs. In the one human case which we have had there was very little excoriation around the stoma of a Beck tube brought over the costal margin. The ideal for which to strive is the connection of the tube directly with the esophageal stoma in which case skin excoriation would not be a factor. However, in such an ideal operation the chance for

success should be much better if one uses a well-healed, preformed tube rather than a freshly made one, for in the latter case there are two suture lines coming together at right angles.

In this study two routes for the tubes fashioned from the greater curvature have been used—(1) the transthoracic and (2) the extrathoracic. In the former group, in eleven dogs, the tube formed at the first operation had its base at the cardiac end of the stomach; at the second operation this tube was brought up through the diaphragm into the chest, then placed along the anterior chest wall, and brought out through the selected interspace onto the chest wall. In the latter group, in ten dogs, the tube had its base at the pylorus. This tube was brought out of the abdomen at the xiphoid notch and carried upward beneath the skin as near to the base of the neck as it would reach. In both instances tubes have been used which had been formed at a first stage operation three weeks before. The tube did not leak or slough in any case. In the case of the intrathoracic tubes there was no interference with the cardiac or respiratory functions, and the surfaces of the tubes were smooth, shiny, and adherent to the pleura of the anterior chest wall.

The technical difficulties of anastomosing the end of the tube to the divided esophagus are so great in the dog that we did not attempt such an anastomosis but confined our observations to the greater curvature tubes to connect the end of the tube and the esophageal stoma, and the tubes to connect the end of the tube, and the esophageal stoma and the position of the left foreleg interferes greatly with any type of anastomosis.

ANIMAL EXPERIMENTS

Series 1. The Formation of a Tube From the Greater Curvature of the Stomach

Thirty-one stock adult dogs weighing between 15 and 20 kg. were used. The animals were put on a diet free from bones and large pieces of meat for a week before operation. On the day before operation they were fed milk only. The stomach was washed out thoroughly immediately before the operation was begun, and the tube was left in the stomach during the first part of the operative procedure. Intravenous nembutal, 1 grain per 5 pounds of body weight, was used as an anesthetic.

Operation.—The abdomen was entered through a high left rectus incision, and a splenectomy was performed. The vessels entering the spleen were divided as close to the spleen as possible, in order to preserve the blood supply to the stomach by way of the splenic artery (Fig. 1). The gastrocolic omentum was divided about 3 cm. from the greater curvature (Fig. 2). This incision extended from the pylorus to the mid-fundus region where the branches of the splenic artery enter the greater curvature. This exposed the posterior gastric wall. Four traction sutures were inserted on the anterior and four on the posterior surface of the stomach about 8 cm. apart and 3 to 4 cm. from the greater curvature. With these sutures as guides, incisions were made parallel to the greater curvature over the anterior and posterior aspects of the stomach. The incisions were made about 3 cm. from the curvature and extended down to the mucosa. The vessels in the mucosa were transfixed with fine silk on both sides of the proposed

mucosal incision (Fig. 3). After the peritoneal cavity was walled off with gauze packs, the stomach was entered on the posterior wall about 5 cm. from the pylorus and divided with scissors throughout one-half of the proposed incision, i.e., halfway to the cardia. A similar maneuver was carried out anteriorly. A running suture of "0" chromic catgut uniting the cut edges of the stomach was started on the stomach side of the incision and carried around the angle up to the middle of the flap. This closed the incision in the stomach and formed half of the tube from the greater curvature flaps. This suture was locked at every third bite to prevent purse-stringing. With half the stomach closed and half the tube formed, the remainder of the outlined incision was completed to within about 8 cm. of the cardia and sutured in the same fashion as the first half of the incision (Fig. 4). This first suture line which united the mucosa was then inverted beneath a continuous Cushing stitch of fine black silk, interrupted at intervals and reinforced at the angles by Halsted mattress sutures of the same material (Fig. 5). The abdomen was closed in layers using silk throughout, and a collodion dressing was applied.

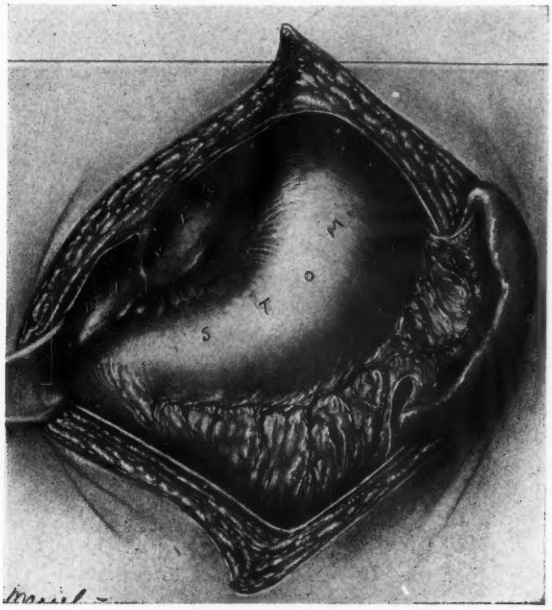

Fig. 1.—The arrangement of the vessels along the greater curvature of the dog's stomach. Note the gap which would result unless the vessels entering the spleen were divided close to it. The main splenic artery is on the underside and is not shown, but its length limits the distance to which the tube will reach.

Comments on the Operation.—In the dog one encounters an arrangement of blood vessels that makes the formation of the tube less simple than in man. Instead of an unbroken vascular arch formed by the gastroepiploic arteries along the greater curvature, there is in the dog a triple blood supply, with the splenic artery supplying the center of the greater curvature (see Fig. 1). Interruption of the splenic branches together with either gastroepiploic artery results in gangrene of the tube

when it is freed at one end. Hence it is necessary to transfer the tube with its splenic arterial branches attached. This is the chief factor which limits the height to which the tube can be transferred. This condition, however, does not exist in man where there is an unbroken arch of vessels from pylorus to cardia above the greater curvature.

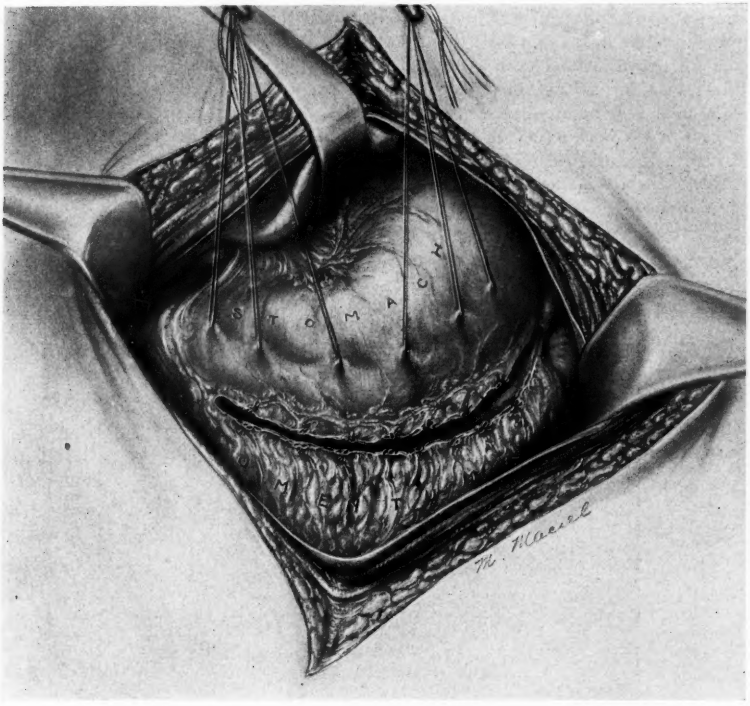

Fig. 2.—Traction sutures have been placed in the anterior wall of the stomach, and the gastrocolic omentum has been divided. This and Fig. 3 are drawings from a human case and fail to show the vascular arrangement as indicated by Fig. 1.

The live cautery was used in some cases to section the mucosa after the large vessels had been ligated. This was associated with no constant change in the healing of the tube, although scarring and adhesions about the tube seemed more marked in those in which the cautery was employed. The only instance of hemorrhage occurred in a tube formed by the cautery technique.

Postoperative Course.—The animals received small amounts of water by mouth on the second day after operation, and the amounts were gradually increased until the entire intake was by this route at the end of four days. Up to this time supplementary intravenous injections of glucose were given. Soft food was well tolerated by the fifth day and a bone-free diet was maintained until further operative procedures were carried out on the tube. The appetite and digestion were normal, and the weight was well maintained.

The postoperative course in all the animals was quite smooth. There was a definite wound infection in two dogs, but this did not extend below the fascia and both wounds healed satisfactorily. There was a hematoma in one wound which responded to aspiration. The remaining wounds healed without infection.

Results.—Tubes were formed by the above outlined operation in thirty-one dogs. In twenty-six of these the tubes healed satisfactorily, and in twenty-two of the dogs further procedures on the tube were carried out. Nine animals died. Three died of distemper after twelve, thirty, and thirty-four days, respectively; one, from obstruction due to a sponge left in the abdomen; four, from peritonitis, resulting from leakage through the suture line of the tubes; and one, from hemorrhage from the suture line of the tube. The tubes were found well healed at autopsy in all except the four dogs which died from peritonitis following leakage through the suture line.

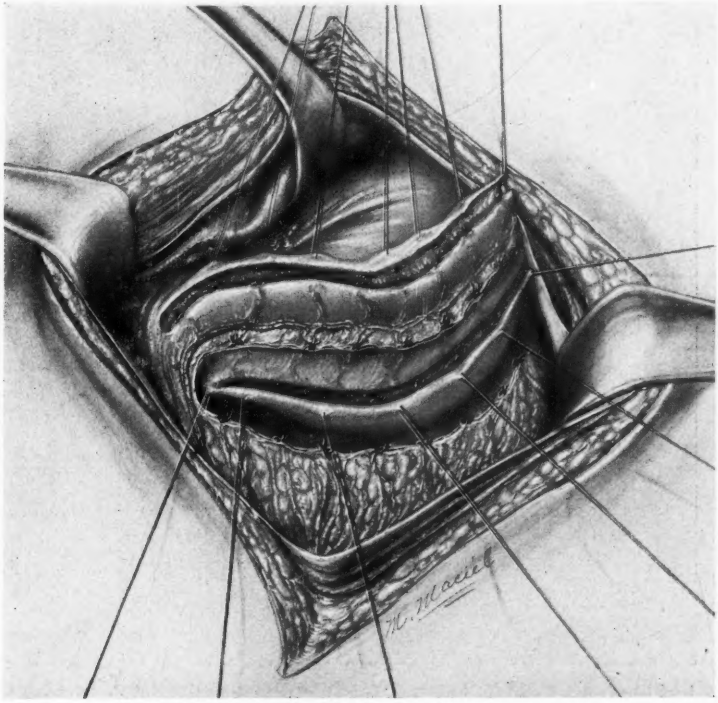

Fig. 3.—Traction sutures have been placed on the posterior wall of the stomach as well as on the anterior. Incisions have been made down to the mucosa, and the vessels in the mucosa have been ligated with transfixion sutures of silk.

Comments.—The chief advantage derived from the formation of a tube at a first stage operation is that one can be assured of a thoroughly healed tube when the tube is used at a second stage procedure. The tube has had an opportunity to adjust its blood supply, to become flexible,

and to become a hollow viscus continuous with the stomach. Like intestine, it can be safely anastomosed to another hollow viscus without fear of leakage at the suture line. The ideal procedure would consist of direct anastomosis of the esophageal stump to a tube formed from the greater curvature of the stomach. If a freshly made tube is thus used, there is considerable likelihood of leakage where the suture line forming the tube joins the suture line forming the anastomosis. The preformed tube obviates this difficulty. Moreover, a two-stage operation lessens the severity of the individual operative procedure. This is important in dealing with patients debilitated by age and by esophageal obstruction. The disadvantage of the first stage procedure lies in the fact that it entails an additional operation.

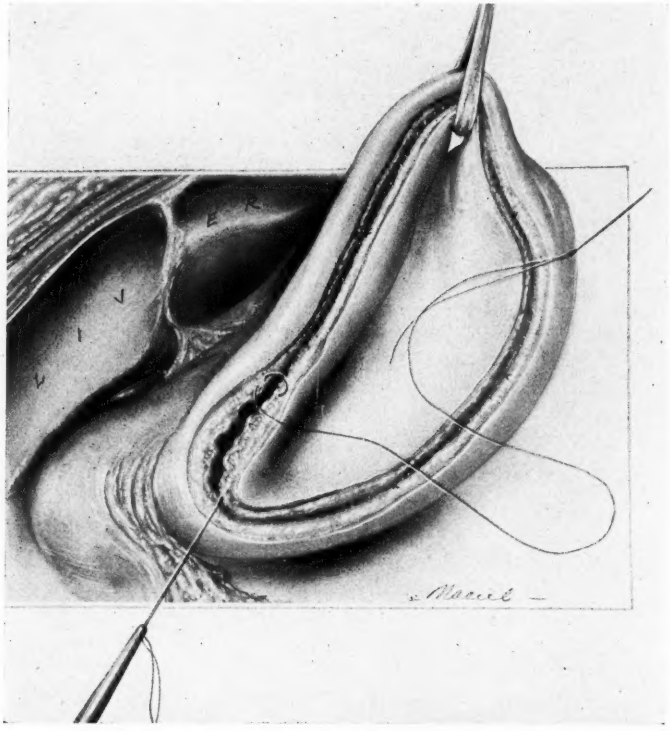

Fig. 4.—The mucosa of the stomach and of the tube are being closed with a continuous suture of fine catgut, which is interrupted at intervals.

Series 2.—The Use of a Transthoracic Route for Tubes Previously Formed From the Greater Curvature of the Stomach. [*The tubes were based on the cardiac end of the stomach (Beck-Jianu).*]

Eleven dogs from Series 1 in which tubes had been formed from the greater curvature of the stomach were used in this series. All of the dogs were in good condition. From two to nine weeks (average twenty-seven days) had elapsed

since the operation at which the tubes had been formed. The same preoperative preparation was used as in Series 1.

Operation.—Intravenous nembutal was used as the anesthetic agent. While the thorax was open, intratracheal oxygen under positive pressure was used. The thorax was opened by an incision through the eighth interspace. This gave adequate exposure, and no rib resection was necessary. The left phrenic nerve was crushed just above the diaphragm. The diaphragm was then incised anteriorly from its central portion. The entire stomach including the pylorus could be drawn

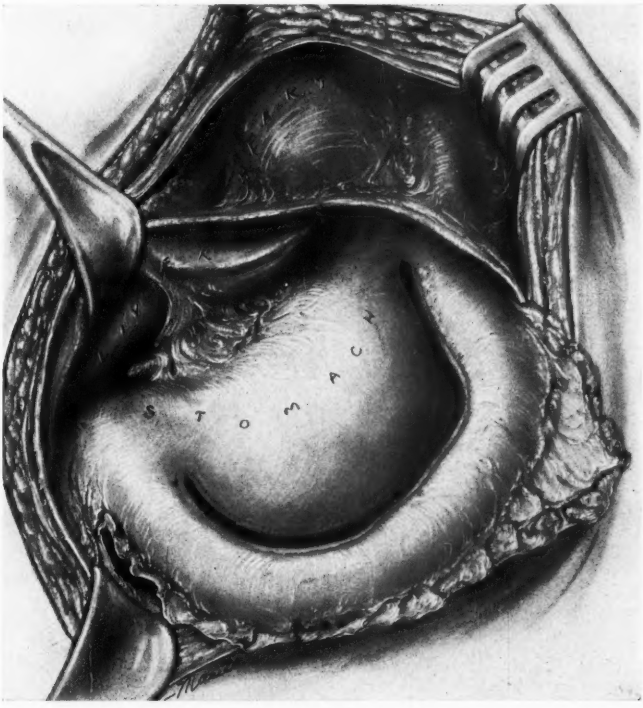

Fig. 5.—The tube has been completed by inverting the first row of catgut sutures beneath a continuous Cushing stitch of silk. Note the interruption of the latter stitch at intervals to prevent purse-stringing. The completed tube has been depicted as seen through the diaphragm as though at the second stage operation.

into the thorax through this incision in the diaphragm (Fig. 5). Any adhesions between tube and stomach were freed, and the tube was divided at its pyloric end (Fig. 6). The wound in the stomach was closed with a purse-string suture of catgut, and this was inverted beneath mattress sutures of fine silk. The end of the tube was covered with a rubber finger cot. The stomach was then returned to the abdomen; the tube was brought up into the chest; and the diaphragm was closed around the tube, first posteriorly and then anteriorly by running sutures of fine silk (Fig. 7). Several interrupted sutures of fine silk were used to unite the cut edges of the diaphragm to the walls of the stomach tube. The interspace to which the tube reached easily was determined, and a small transverse incision was made through the selected interspace in the left anterior axillary line. The tube was drawn through this incision so as to project for 2 to 3 cm. above the

skin surface (Fig. 7), and the chest wall was closed around the tube in layers with silk sutures, the first of which fixed the tube to the muscles of the chest wall. The thoracic wound was then closed without drainage in layers with continuous silk sutures. Any air remaining in the thorax was aspirated immediately after the wound had been closed.

Postoperative Course.—A regime of feeding and of administration of parenteral fluids was carried out as in Series 1. After one week the animals were placed on an unrestricted diet.

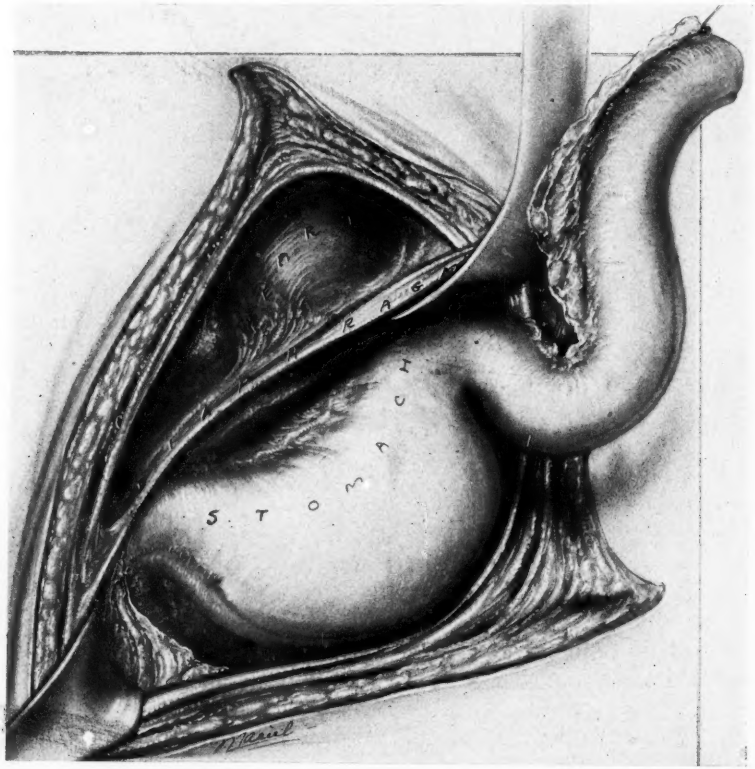

Fig. 6.—The tube has been divided at the pyloric end and is ready to be placed in the thorax.

Results.—Tubes were transferred by the transthoracic route in eleven animals according to the technique described. Of these eleven animals, one was alive and well five months after operation and one was sacrificed three months after operation. The remaining nine animals have died. The chief cause of death was an open pneumothorax which resulted in four cases from digestion of the chest wall around the stoma of the stomach tube, and in one additional case from improper closure of the chest wall around the tube. The digestion of the thoracic wall

by the gastric contents took place slowly and steadily in spite of all therapy. Finally, a sucking wound was produced in about twenty-seven days, and death resulted from this. One dog died five weeks postoperatively from perforation of a gastric ulcer which occurred in the stomach

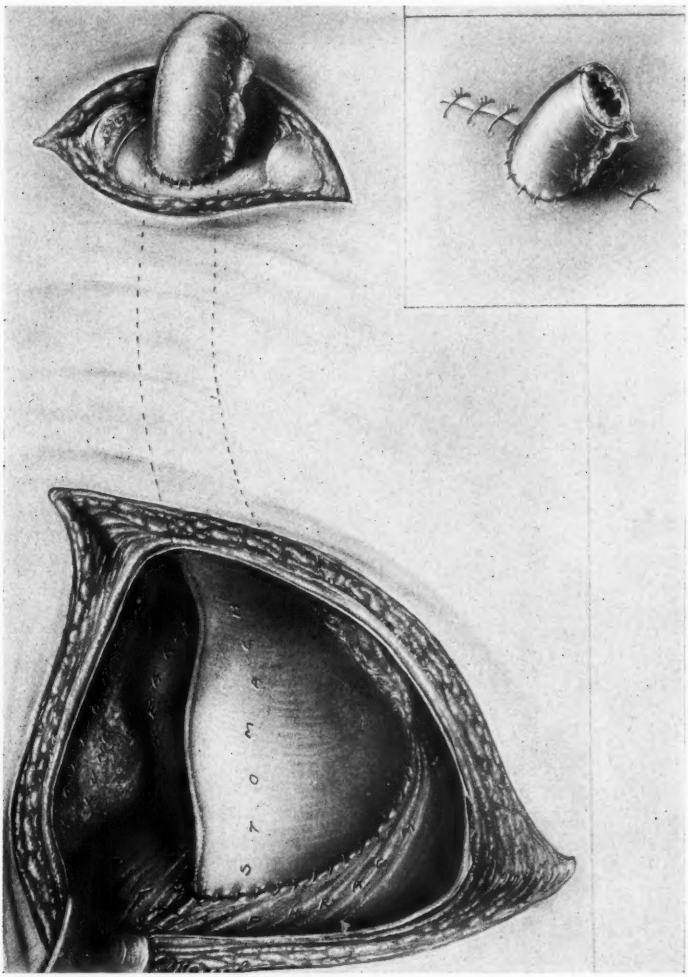

Fig. 7.—The tube, with a small portion of the stomach, has been brought through the diaphragm, placed along the inner aspect of the anterior thoracic wall, and then brought out through an interspace. The insert shows the projection of the tube above the skin level.

just below the diaphragm. One animal succumbed to a bilateral empyema which developed four days after operation and which was due to soiling at the time of operation. In the remaining two animals, one of

which died eighteen days after operation and the other in three days postoperatively, the cause of death was somewhat obscure. One of these animals was found to have a dilated scarred heart, and the other, an incomplete pyloric obstruction.

Fig. 8.—An intrathoracic tube at autopsy three months after operation. Note its smooth shiny surface. The lung was adherent to it at one point.

Comments.—The operation is a feasible one but is not satisfactory in the case of the dog because of leakage of gastric contents from the tube with resulting excoriation of the skin about the stoma. The tube comes off the stomach and runs a straight course through the thorax to a point which, when the dog stands, is lower than the stomach. Thus there is nothing to prevent leakage of the stomach contents. The tubes themselves were satisfactory in that they remained well healed and patent in

all cases (Fig. 8). They did not interfere with the function of the heart or lungs. The chief disadvantage of this type of operation is that there is no angulation of the tube nor any valvelike action to prevent regurgitation of stomach contents through the tube. Another objectionable feature is the use of an intrathoracic procedure to accomplish an end that can be gained just as satisfactorily by an extrathoracic one.

Series 3. The Use of an Extrathoracic Route for Greater Curvature Tubes Formed at a Previous Operation. (The tubes were based on the pyloric end of the stomach.)

Ten of the dogs from Series 1 were used in this series. All had tubes formed from the greater curvature of the stomach at a first stage operation performed from two to four weeks (average twenty-four days) previously. All animals were healthy and in good condition. The preoperative care was identical to that in Series 2.

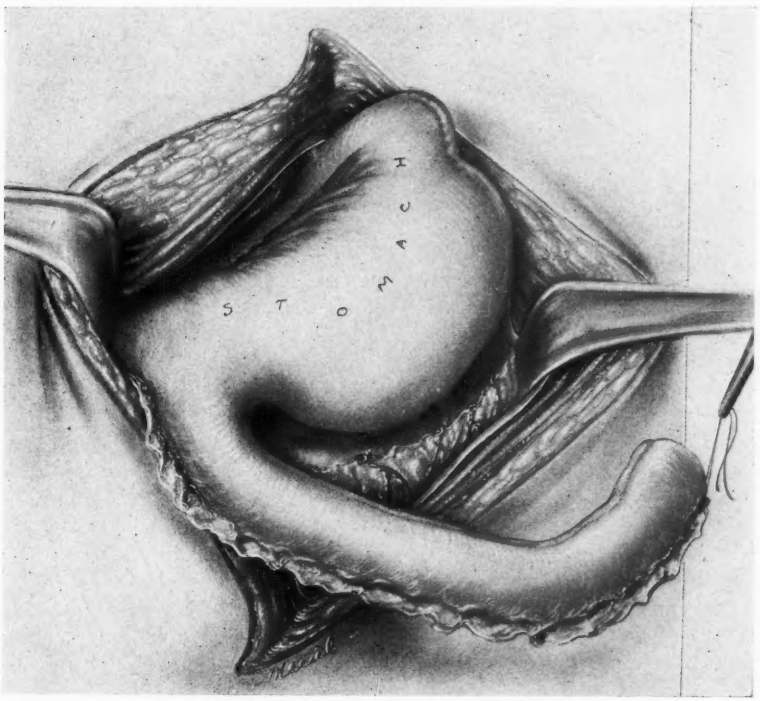

Fig. 9.—The tube has been divided at its cardiac end and is ready to be placed beneath the skin of the thoracic wall.

Operation.—Intravenous nembutal was used as the anesthetic agent. The abdomen was entered through a high midline incision, and any adhesions between the stomach and the tube were separated. The tube was then divided at its cardiac end by the same technique previously described for the transthoracic tubes (Fig. 9). An incision was now made on the thoracic wall from the cephalic end of the abdominal

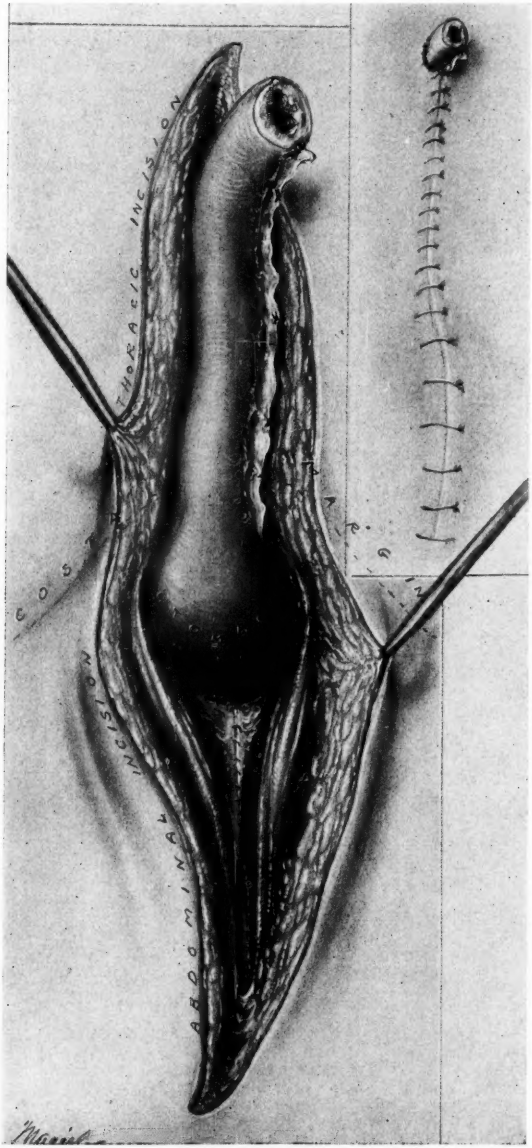

Fig. 10.—The abdominal wound has been closed around the stomach and tube. The tube has been placed in the incision on the thoracic wall. Note the bulge where the tube crosses the costal margin. The insert shows the completed operation.

incision upward to the desired height. This was carried down to the muscles of the chest wall, and the edges of the incision were undermined widely in order to mobilize the skin on the thoracic wall enough to cover the tube. The tube was then drawn out of the abdomen to the desired length, and the abdominal wall was closed in layers with silk around the tube (Fig. 10). The tube was now placed in the wound on the thoracic wall, and the skin was sutured over it with interrupted silk sutures.

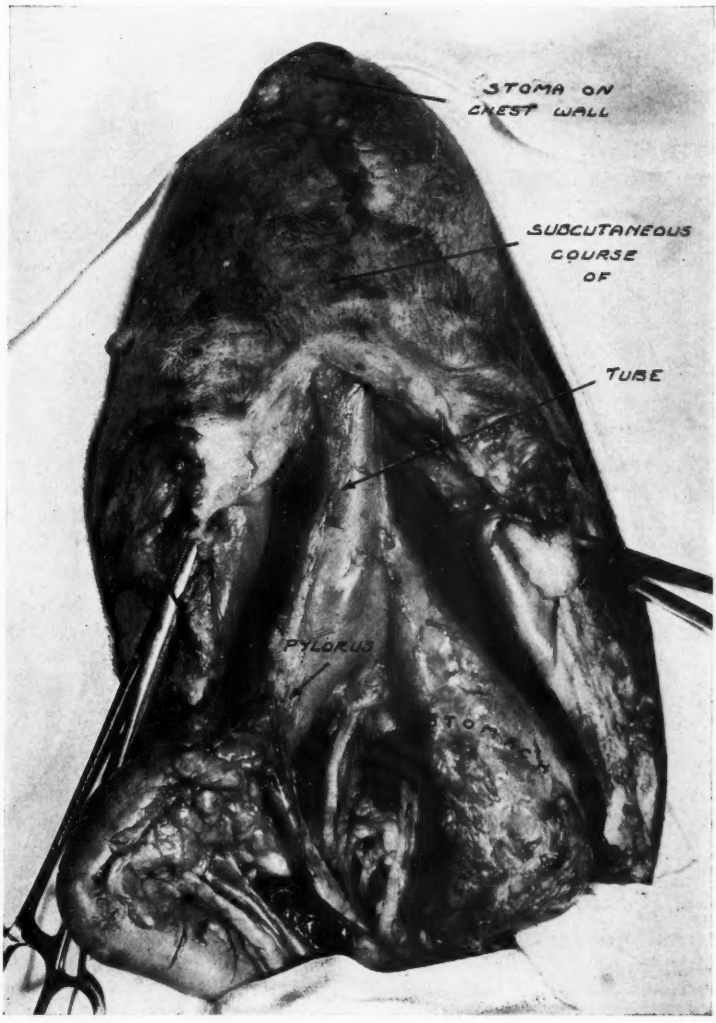

Fig. 11.—A subcutaneously placed tube with its base at the pyloric end of stomach as seen at autopsy one month after operation. The abdominal wall has been cut away for clarity.

In a few instances a subcutaneous tunnel was made for the last few inches of the tube. This was very satisfactory, producing a good stoma. About 2 cm. of the tube were left projecting above the skin surface.

Postoperative Course.—The same postoperative care was used in this series as in Series 1 and 2. The chief postoperative complication was separation of the edges of the thoracic wound into which the tube had been transferred. This separation was due to two factors—(1) the large mass of gastrocolic omentum which it was necessary to transfer with the tube in order to preserve its blood supply, and (2) the fact that the skin on the dog's chest is stretched so tightly that it is difficult to make it cover any unusual distance after being undermined.

Results.—Severe excoriation of the skin did not occur in any of these animals, but there was some separation of the skin flaps on the chest wall in all cases. In two instances there was complete separation of the skin flaps so that the tube hung free from the thoracic wall; but the tube itself did not show any evidence of disruption along the suture line. Two animals died from hemorrhage on the first and second days after operation due to tension necrosis of the vascular pedicle of the tube; this was an error in technique. Two animals died of pneumonia on the ninth and twenty-sixth days, respectively, after operation. Three animals died on the seventeenth, thirtieth, and thirty-third days, respectively, after operation. The causes of their deaths could not be determined at autopsy. One animal was sacrificed fifty days after operation. Two animals are alive and well, one two months and one three months after operation.

Comments.—There were little excoriation of the skin around the stoma in these animals, and no leakage of gastric content from the stoma. This was in marked contrast to the findings in Series 2. The lack of leakage from the tube was thought to be due to the valve-like action on the tube by the costal margin. This could be shown by attempting to pass a catheter into the tube. The catheter passed easily until it reached the point where the tube crossed over the costal margin where it met a distinct obstruction. X-ray studies carried out on the tube postoperatively confirmed this impression.

The tubes themselves were satisfactory in every case from the points of view of patency and of integrity of the suture line (Fig. 11).

SUMMARY

We believe (1) that the formation of a tube from the greater curvature at the first stage of the operation is practical and such a tube possesses sufficient blood supply so it can be used several weeks later at the second stage operation without fear of leakage; (2) that such tubes can be brought up through the thorax without fear of leakage or interference with the cardiorespiratory mechanism; (3) that with the Rutkowski method such tubes can be safely brought out of the abdomen and placed under the skin of the chest wall to extend to a high level on the thoracic wall, and (4) that in dogs, if the Rutkowski type of tube is used and brought up beneath the skin, less leakage will occur and less excoriation of the skin than if the Beck type, brought out through the thorax, is utilized where digestion of tissues around the stoma is very severe.

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DISCUSSION ON "CANCER OF THE THORACIC ESOPHAGUS AND THE UPPER END OF THE STOMACH" BY DR. H. BRODIE STEPHENS;* "EXPERIENCES WITH EIGHT CASES OF RESECTION OF THE ESOPHAGUS FOR CARCINOMA" BY DR. DALLAS B. PHEMISTER;† AND "AN EXPERIMENTAL STUDY OF TUBES MADE FROM THE GREATER CURVATURE OF THE STOMACH" BY DR. B. NOLAND CARTER, DR. OSLER A. ABBOTT, AND DR. C. ROLLINS HANLON

Unfortunately the manuscript entitled "Carcinoma of the Esophagus" by Dr. Harold W. Wookey, Toronto, Ontario, is not available for publication.

Editor's Note.

DR. CARL EGGERS, New York, N. Y.—It has been very interesting and illuminating to listen to the papers presented this morning on carcinoma of the esophagus. Up to a few years ago, it was rare to hear the subject discussed because only a few surgeons ventured into this field.

The most favorable aspect of the entire presentation is the interest which is being shown by surgeons from all parts of the country. This increased interest was also noted at last year's meeting, when men all over the room rose to report individual or small groups of cases.

Today, however, larger series are presented, with results which are definitely encouraging. It was hoped when Dr. Torek presented his first successful case in 1913 that it would shortly be followed by a larger series of favorable ones. Unfortunately, that did not prove to be the case. Dr. Torek himself was not favored with an additional successful case.

Now, however, the condition appears to have changed, and surgeons who have hitherto held themselves aloof have found encouragement in the reports of successful cases and perform the operation.

It is well known that the operation for carcinoma of the esophagus is a difficult one, and, as you have realized from the larger series of Dr. Phemister and Dr. Stephens, not all patients on whom one operates have a removable lesion. As a matter of fact, one finds many disappointments and has to keep one's optimism in the face of discouraging findings.

At the present time the majority of cases which come under a surgeon's observation cannot be considered for operation at all, because they have waited too long and in addition to a far-advanced local growth their general system has suffered from malnutrition or they have degenerative changes due to senility. It is only the occasional case which may be carried through to a successful conclusion, and, of this group, only a certain percentage live for a sufficient length of time to furnish our basis for optimism.

*See page 469 for article by Stephens.
†See page 484 for article by Phemister.

There is one thing that one may definitely state, namely, that the feasibility of the successful removal of a carcinoma of the esophagus has been definitely established. That is the all-important, basic factor which one has to recognize. During the last years improved methods of preoperative care, changes in or additions to the operative procedure as originally proposed, the introduction of chemotherapy, and advances made in the administration of anesthesia have helped to make the operation a little less hazardous than it formerly was.

Dr. Stephens brought out various interesting points and showed the value of cooperation. I think each one of us has learned from the papers presented today, for each essayist presented his own definite ideas which might differ a little from those of others but help the general knowledge of this subject along.

Dr. Stephens spoke, for instance, about a certain type of gastrostomy that he was doing. The question of gastrostomy in connection with carcinoma of the esophagus requires a great deal of consideration. In our successful cases of mid-esophagus resections by the Torek method, the patients are left with an upper esophageal stump and a gastrostomy opening. The existing gap may be bridged by a rubber tube, and the patients are reasonably satisfied. However, they are not happy, and, if we can make them happy by a reconstructive procedure, we are gaining a great deal.

We have been in the habit of doing a Janeway gastrostomy, which is a very satisfactory gastrostomy as such, but it is not suitable for reconstruction purposes. In the consideration of the subject of carcinoma of the esophagus at the present time, with the many successful cases that have been done, the establishment of a gastrostomy has to be considered from the standpoint of the role it may play in subsequent esophageal reconstruction operations.

There were three definite ideas brought out today which are not all new but do bring out the thoughts which carry us along in this work. One of them was presented by Dr. Carter and consists of the reconstruction of an esophagus with the aid of a tube made from the greater curvature of the stomach, the so-called Beck-Jianu gastrostomy. This method may prove to be the one that will be utilized a great deal in the future. It is an ingenious method, and it gives a long tube which may be so long that it can be used for direct anastomosis with the upper esophageal stump. If that is not possible, it may extend only part way up the chest wall and a skin tube may be required to bridge the gap.

Another method is the one which was mentioned by Dr. Wookey, which has also been used by other men for various conditions. It consists of the utilization of the lower esophagus stump as a gastrostomy and is therefore really a lower esophagostomy. This method seems to have far-reaching possibilities. I know from correspondence with Dr. Carter that he has used it in a case of congenital atresia of the esophagus. We have advocated it for similar conditions. Garlock has used it in carcinoma of the esophagus, and now Wookey, apparently entirely independently, has also made use of it.

The employment of a skin tube, of course, is one of the oldest methods known in reconstruction of the esophagus. The union of the skin tube with the gastrostomy has been followed by considerable difficulty resulting from regurgitation of gastric contents with ulceration of the skin and fistula formation. Theoretically the use of the lower esophageal stump is the most suitable and best method for union, if that proves satisfactory.

If we all work along these various lines, take ideas home with us and work with them, we shall eventually know which is the best method to be used in reconstruction. I think presentations such as those made this morning, grouped together in our JOURNAL so that surgeons may keep them readily available, are going to prove stimulating and valuable to all the members of our Society.

I want to congratulate the various men who have contributed this morning and thank them for the stimulus they have given all of us. I was particularly inter-

ested in Dr. Wookey's presentation of carcinoma of the upper esophagus. That is a very difficult and discouraging subject. I have had some experience with it, and that not very happy. I have tried both methods. I have removed the esophagus together with the larynx and the pharynx, and I have also tried to save the larynx, and have always come to the conclusion that the operation was incomplete. But with the method that Dr. Wookey has described, one certainly feels encouraged to attempt removal of these lesions.

DR. EDWARD D. CHURCHILL, Boston, Mass.—As Dr. Eggers has said, this has been a most stimulating morning, and I have learned a great deal from hearing of the experience of the essayists. Certainly there can be no conflict in the general principles involved in the presentation this morning, and, in short, if we could take Dr. Graham's admirable call to duty yesterday on carcinoma of the lung, and replace "carcinoma of the lung" with "carcinoma of the esophagus," everything said then can be said now.

While there is no conflict in principles, we are faced with a kaleidoscopic pattern of techniques and details. I shall not introduce any direct evidence from our own cases but shall say at the outset that my comments are based on a series with which Dr. Sweet and I have struggled and in which we have now five living patients with high thoracic esophageal cancer, and six of the esophagocardiogastric group.

First, as to the approach, and I hardly need to point out that there are pros and cons to every technical detail. At the present, I have settled on the left transpleural approach largely because it provides for a more adequate resection of the lower end.

Esophageal cancers are treacherous in that they extend under the mucous membrane for some distance from the site of the primary growth. The left-sided approach allows one to invert the lower end into the stomach where it is probably safer than it is in the mediastinum. The right lung carries more of the respiratory burden than the left, and in a poor risk patient it is probably better to cripple the left hemithorax than the right.

There is easier access to the neck from the left. The barrier of the aortic arch has been handled, as Dr. Stephens suggested today, by mobilization following section of the intercostal vessels.

Invasion of the left bronchus may be a pitfall, and I suggest that bronchoscopy be performed preoperatively when there is reason to believe that the growth lies in contact with the left primary bronchus.

The level of approach is a detail. Personally, I differ from Dr. Phemister and prefer to go higher in the midthoracic growths, choosing the level of the sixth rib, and lower for the cardioesophageal growths, resecting either the ninth or tenth rib.

The advantage of a preliminary laparotomy in the high esophageal growths should be put into the balance. A preliminary laparotomy will give information regarding the involvement of the group of nodes at the cardioesophageal junction. We, perhaps, have been too conservative in considering metastasis in this cluster of nodes a contraindication to radical resection. There are certain instances in which Dr. Stephens' suggestion of resecting these nodes should be considered. Dr. Phemister has also carried that out.

The advantage of preliminary laparotomy also lies in that it provides a dignified retreat with a palliative gastrostomy when inoperable malignancy is displayed. If the growth is resectable, the gastrostomy provides the lower stoma for the turnout operation.

Dr. Wookey has shown very excellent results by using the lower end of the esophagus for the inferior stoma. The only case in which I have carried the plastic reconstruction of antethoracic esophagus to completion was done by this

method, and there is no doubt that there is a kinder union of the epithelium of the esophagus and the skin than occurs with a gastrostomy stoma.

However, I am departing from this method for various reasons. First, there is a temptation to section the esophagus too close to the growth; secondly, the inferior esophageal stoma in one other case showed a tendency toward stenosis.

We have had an experience of several years with the Beck-Jianu greater curvature tube gastrostomy performed in a one-stage operation. It is an excellent palliative gastrostomy and provides a high inferior stoma for a later plastic reconstruction.

I can see no advantage to an intrathoracic bed for this tube. The extent of the elevation of the tube is determined by the left gastroepiploic artery, and it can be brought up to the level of the nipple in the human being in a subcutaneous bed. While I think the experiments of Dr. Carter and his associates are admirable, I shall still continue to use the subcutaneous bed. I do not like concealed plumbing and am afraid of the soiling of the thoracic cavity even with a two-stage procedure.

In the esophagocardiogastric group of cases, I agree there should be no preliminary gastrostomy. I do think, however, that, if there is some reasonable doubt as to operability, a preliminary laparotomy may well have a place. If the growth is shown to be operable, a jejunostomy can be performed and provides an admirable method for feeding both in preoperative and postoperative periods.

The possibility of carrying esophagogastric resection through to a total gastrectomy has been demonstrated, although in the single case in which I have done it, the patient died postoperatively. In transthoracic resection of the cardiac end of the stomach for the high gastric lesions that extend into the esophagus, there are hazards in leaving a small gastric pouch in the presence of divided vagal nerves. Pyloric spasm is likely to result, and, if these patients swallow food into too small a gastric pouch, they may have distressing symptoms. So if the pouch is going to be too small, one had better plan for a jejunoesophageal anastomosis.

Dr. Phemister's suggestion of the use of umbilical cord tape is excellent. I add to that the advantages of slipping the ends of the tape through a Shenstone tourniquet. This attaches a handle to the esophagus and provides a gentle, occlusive pressure.

In relation to the plastic reconstruction, it is my belief that the skin tubes are going to work out satisfactorily. There are an infinite number of technical details that are important. The one that we are worrying about most is provided by the man with a hairy chest, and I am afraid that a skin tube must be moved from the nonhairy axillary region for this purpose. I hesitate to turn in a hair-bearing area.

During these long plastic procedures, I suggest that the patient be kept swallowing. A patient forgets how to swallow. The patient should be given food or gum each day to spill through the cervical stoma to keep the muscles of deglutition active during these procedures which may extend over several months.

DR. HERBERT WILLY MEYER, New York, N. Y.—In line with these splendid papers, and especially the remarks of Dr. Stephens and the discussion of Dr. Churchill, I should very briefly like to report an operation which turned out to be a total gastrectomy with resection of the lower esophagus, followed by an intrathoracic esophagojejunostomy, performed in one stage.

The patient, a woman 52 years of age, was admitted to the Lenox Hill Hospital with the diagnosis of carcinoma of the stomach, and we thought that we might have to perform a total gastrectomy.

You will see on the slide of the x-ray picture what seemed to be an extensive carcinoma of only the stomach. We planned to do a total gastrectomy, with an intra-abdominal esophagojejunostomy.

When we entered the abdomen, we found on exploration that the tumor went up to the diaphragm and passed onto the esophagus. On dividing the peritoneum at the esophageal hiatus and freeing the esophagus in the posterior mediastinum, we found the tumor extended 2 inches onto the esophagus. We could, however, get our fingers about the tumor onto normal esophagus. We were not prepared to do a radical extirpation of this entire mass at this time, so we took out a few lymph nodes for diagnosis and closed the abdomen.

After the seriousness of this condition was discussed with the family, it was decided to risk a radical procedure.

Knowing that this tumor extended onto the lower esophagus, we had further x-ray studies made, and this time they demonstrated a narrowing without any obstruction, but only some hesitancy of the barium going into the stomach. So after most thorough preparation of the patient, we operated a second time some weeks later. The tumor was freed all the way to the diaphragm after dividing the pylorus; the posterior mediastinum was again entered; and the esophagus was freed up about the tumor. Then we wrapped the stomach in gauze and tied it with tape. An enterostomy was performed about 12 inches below the ligament of Treitz, brought up antecolic, and the loop of the jejunum was tied to the gauze which was wrapped around the stomach.

Then we closed the abdomen, turned the patient onto the side, incised the seventh interspace, divided the seventh, sixth, and fifth ribs posteriorly, crushed the phrenic nerve, split the diaphragm, and then were able very easily to put the entire stomach up into the left pleural cavity.

We had previously put a duodenal tube into the stomach to aspirate the fluid and keep the stomach empty. We now pulled the tube into the esophagus and kept continual suction on it to prevent soiling as far as possible. Then, with a modification of the technique of Dr. Roscoe Graham, we performed an intrathoracic esophagojejunostomy, using the loop of intestine which we had prepared and brought up into the chest with the stomach.

There was quite some tension, and, if anyone is going to attempt this operation in the future, I would suggest that, instead of bringing the loop antecolically, it is better to bring it retrocolically. On the autopsy table we have found that, if you bring it retrocolically, the root of the mesentery slides up through the opening in the transverse mesocolon, and there is less tension.

Here you see a microscopic section of the tumor, passing up the esophagus and involving the stomach extensively.

As Dr. Churchill mentioned, you see the intact mucosa of the esophagus with the tumor infiltrating under the mucosa, without ulceration of the mucous membrane.

On this slide you see the patient after the operation with the abdominal wound healed.

Here you see the posterior wound healed. We had put in airtight drainage. As far as the anastomosis was concerned, she made a satisfactory recovery.

You see here a photograph of the patient taken four months after the operation. She vomited sometimes when she ate, and we found by x-ray studies that, when the patient was lying down or was reclining, the barium she swallowed into the small intestines would regurgitate into the esophagus. When we placed her in the upright position, the barium would run back into the intestine.

Here one sees an x-ray taken four months after the operation with barium passing easily and quickly into the jejunum in a case of an intrathoracic esophagojejunostomy. The patient lived five months and then died of a generalized carcinomatosis involving the lungs, the peritoneum, the omentum, and the liver.

DR. ALTON OCHSNER, New Orleans, La.—Just a word about technique, which Dr. Churchill has emphasized. We have found too, as Dr. Wookey has, that the approach from the right side is easier. We have done the operation in five cases,

two from the left and three from the right, and certainly in our hands it is technically much easier to approach from the right.

I was interested in Dr. Wookey's statement concerning the removal of the tumor before he brought the esophagus out through the cervical wound. Dr. Wangensteen observed one case in which apparently an implant of the tumor occurred in the cervical wound. It is desirable in every instance to amputate that portion of the esophagus bearing the tumor before it is brought through the cervical wound, and the placing of the silver wire around it seems to me a valuable suggestion.

We have felt in those cases in which a resection of the distal portion of the esophagus is done transthoracically, that a laparotomy should be done not only as an exploratory procedure, but in order to free the gastrohepatic and gastrocolic omenta. In one instance when the tumor extended well down along the lesser curve, we freed the two omenta respectively, and were able to mobilize the stomach for a considerable distance up to the thorax, much more than we felt we might have done had this not been done previously.

I was very much interested in Dr. Carter's and Dr. Abbott's presentation. Dr. Owens and I presented a paper several years ago in which we reported a patient who had had an anterothoracic esophagoplasty, and after a review of the literature we came to the conclusion that a dermato-esophagoplasty was not a safe procedure because of the bad results which were uniformly obtained when a skin anastomosis was made with either the stomach or a stomach tube. We felt at that time that it was desirable and almost essential to interpose a piece of wall, and preferably jejunum.

I think Dr. Wookey's experience has demonstrated to us that it is perfectly feasible to do a dermato-esophagostomy without any danger, and I am convinced, as Dr. Churchill has emphasized, that the reason he has obtained a good anastomosis without leakage was because he has used the esophageal end to make the anastomosis.

If one takes a skin tube or takes the stomach itself or a stomach tube and anastomoses to the skin, one is likely to have a digestion of the skin and leakage along the suture line.

DR. I. A. BIGGER, Richmond, Va.—My experience with resection of the esophagus for carcinoma of the thoracic portion of that structure is limited to two patients, both of them operated upon during the past year. Several years ago I resected two mid-esophageal carcinomas, and at that time I used the right-sided extrapleural approach described by Dr. Lilienthal. In these two later cases we used a right-sided transpleural approach and this seemed much easier than it would have been from the left side, for, as Dr. Wookey and Dr. Ochsner have pointed out, on the right we do not have to deal with the arch of the aorta and division of the azygos vein is simple and apparently harmless.

The question of inversion of the esophagus seems to me to present no great difficulties from the right side. I have not actually inverted it into the stomach, because I wished to save a short segment of the esophagus for possible transplantation later on, but inverting it to within 3 or 4 inches of the lower end of the esophagus was not difficult. I believe that it could easily be inverted into the stomach if one wished to do so.

In both of our recent cases the lesion was so high that we were left with a very short proximal stump and in both a stricture developed at the stoma. In one this stricture was relieved by the use of a whole thickness skin graft.

Both of these patients developed metastatic lesions and died, one after only six months and the other after about nine months.

DR. H. BRODIE STEPHENS.—I should just like to join the other discussants to congratulate Dr. Wookey on his beautiful results. I am sure we all appreciate very much his demonstration.

I think a word might be said again as to the advantages and disadvantages of the right or left side approach in these lesions. Dr. Carter has shown, in one of his patients, lymph nodes at the cardioesophageal junction which were the seat of metastases from a tumor located behind the arch of the aorta. If you recall, one of the cases I presented had a similar spread, and the only spread, as proved by necropsy.

One does not obtain the exposure of the lower end of the esophagus through the right-sided approach that one does through the left, and, if we are going to do a complete operation, it seems to me we shall have to employ the left-sided approach.

DR. DALLAS B. PHEMISTER.—I believe that the ideal for which to strive in these cases is to reduce the operation to a one-stage procedure, if possible. For that reason, I am rather against preliminary gastrostomy. In the high lying lesions there is usually enough of the lower esophagus left for the performance of an inferior gastrostomy. That can be very easily done while the chest is open, by making an incision just below and to the left of the scaphoid, and carrying a long hemostat through between diaphragm and liver to the esophageal aperture and grasping the purse-string suture of the liberated esophageal stump and pulling it through to the surface.

That gives a much more satisfactory opening into the stomach than does a gastrostomy, because it does not leak.

In the cases of carcinoma of the lower esophagus and of the cardiac end of the stomach, a satisfactory exploration can be made through the chest and the diaphragm. If one wants to do a gastrostomy for feeding those cases in which resection and anastomosis is performed, which I think as a rule is not necessary, one can quickly make a catheter gastrostomy before closing the diaphragm.

DR. C. ROLLINS HANLON.—Apropos of the remarks of Dr. Churchill expressing his preference for the antethoracic tube in reconstruction of the esophagus, I would like to reiterate that we also prefer that method, for the reasons advanced by Dr. Abbott.

In regard to Dr. Ochsner's remarks about the difficulty of anastomosing a gastric tube to the skin because of erosion, we are also in agreement with that viewpoint. However, as Dr. Abbott mentioned, the ideal would be to anastomose the gastric tube directly to the esophagus; if that could be accomplished, the factor of erosion of the skin would not be considered.

In cadavers, that is feasible in a good many cases, as we have shown and as has been shown before. However, we have not done it in any operative cases.

RESECTION OF THE ESOPHAGUS FOR CARCINOMA

An Analysis of Experiences in Eleven Cases

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CARCINOMA of the esophagus is unusually prevalent in North China and is seen more frequently than carcinoma of the stomach at the Peiping Union Medical College Hospital. It is difficult to ascertain the cause of this high incidence. However, the majority of the patients are farmers and laborers. It is quite possible that the prevalence of oral infections, the relatively rough character of the food, and the frequent consumption of the strong native white wine among these classes of people may be an important etiologic factor.

Our experience in the treatment of this disease has been very disappointing.[1] Radiation therapy of various forms and gastrostomy rarely are of much value even for palliative purposes. Radical surgical treatment has been regarded as impractical because of the prohibitive high operative mortality. However, the recent advances in this field of surgery, especially in the American clinics[2-5] have considerably brightened the outlook for this heretofore hopeless disease. During the past two years we have also carried out resections of the esophagus for carcinoma in eleven cases with encouraging immediate results (Table I). A general review of the subject and detailed report of our first three cases appeared in a previous paper.[6] In the present communication, our personal experiences in these eleven cases are analyzed.

SELECTION OF PATIENTS

In spite of the fact that the patients were carefully selected from a large number of cases, all except one had advanced lesions. Undoubtedly the insidious nature of the disease renders an early diagnosis difficult. However, usually the fault lies in the delay on the part of the patient or negligence on the part of the physician. As Garlock[3] has rightly emphasized, dysphagia in men over 35 years of age should be considered as carcinoma of the esophagus until proved otherwise by roentgenologic and esophagoscopic examinations. An important fact to be remembered is that carcinoma of the esophagus is not a rare disease, being surpassed in frequency in males only by cancer of the stomach, lung, or rectum.[5]

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It is well known that the duration of the symptoms does not represent the extent of the disease, nor does the degree of dysphagia always indicate the stage of the lesion. In one of our cases, an extensive ulcerative tumor was found at the time of the operation while the patient had only a mild dysphagia. The factors determining the operability in a given case are the roentgenologic and esophagoscopic findings and careful evaluation of the patient's general condition. Marked cachexia and clinical metastasis naturally preclude resection. Serious disturbances of the circulatory, respiratory, or renal function contraindicate the operation. However, in view of the hopeless prognosis without the operation, we feel that the benefit of an exploration should be offered to the borderline cases.

PREOPERATIVE PREPARATION

Attention to the state of nutrition and hydration of the patient is essentially the same as in any other major thoracic or abdominal surgery. Blood transfusions, parenteral fluids, and vitamins are frequently indicated. Oral infections should be treated vigorously for obvious reasons. The administration of sulfonamide drugs for two or three days before the operation is valuable in decreasing the bacterial activity in the upper respiratory and food passages. The esophagus should be at maximum rest for the week before the operation. During this period, only liquid diet of high caloric value is prescribed by mouth. Irrigation of the esophagus for three nights preoperatively as recommended by Garlock[2] is helpful in clearing up the infection and edema in and above the tumor.

The establishment of a gastrostomy or a jejunostomy in a preliminary operation remains an unsettled problem. In tumors of the middle third of the esophagus, in which there is definitely no chance of esophagogastric anastomosis, we establish a permanent gastrostomy in a separate operation ten days to two weeks before the resection. Garlock[7] recently recommended omission of a preliminary gastrostomy and suggested exteriorization of the lower stump of the esophagus in the epigastrium at the time of the resection. We operated upon two patients (Cases 3 and 5) in exactly the same manner. However, we feel that it increases the hazards of an operation which is already extensive, with no significant practical advantages and should not be employed routinely. In the case of carcinoma of the lower third of the esophagus or cardia of the stomach, in which esophagogastrostomy is to be performed after the resection, we prefer to carry out the operation in one stage. If it is necessary to establish a preliminary feeding channel because of the marked esophageal obstruction, a jejunostomy instead of a gastrostomy should be done. However, this was necessary in only one of our cases.

Artificial pneumothorax has been used as a preoperative measure by a number of surgeons including ourselves.[6] However, in view of the fact

TABLE I

SUMMARY OF ELEVEN CASES OF RESECTION OF THE ESOPHAGUS FOR CARCINOMA*

CASE NO.	NATIONALITY	SEX	AGE (YEARS)	LOCATION OF TUMOR	TYPE OF TUMOR	OPERATION	RESULTS (FOLLOW-UP DATA TO SEPTEMBER, 1941)	REMARKS
1	Chinese	M	39	Cardia of stomach and lower end of esophagus	Adenocarcinoma	Feb. 13, 1940, gastrostomy; Mar. 13, 1940, thoracicoabdominal resection and dorsal esophagostomy	Died of tuberculous pneumonia 7½ months after operation	Local recurrence in the stump of esophagus and metastasis in the pelvic cul-de-sac before death. Autopsy revealed microscopic metastatic lesions in lungs and adrenals
2	Chinese	M	65	Middle third of esophagus	Squamous	Mar. 13, 1941, gastrostomy; Mar. 31, 1941, thoracicocervical resection	Well 6 months after operation	
3	Chinese	M	63	Middle third of esophagus	Squamous	Apr. 28, 1941, thoracicocervical resection and epigastric esophagostomy	Well 4½ months after operation	
4	Chinese	M	62	Middle third of esophagus	Squamous	June 7, 1941, gastrostomy; June 25, 1941, thoracicocervical resection	Died of tension pneumothorax 36 hours after operation	Autopsy revealed no evidence of tumor left behind.
5	Chinese	M	46	Middle third of esophagus	Squamous	July 20, 1940, thoracicocervical resection and epigastric esophagostomy	Died of bilateral bronchopneumonia 3 days after operation	No autopsy

6	Chinese	M	58	Lower end of esophagus and cardia of stomach	Squamous	Apr. 26, 1940, thoracicoabdominal resection, esophagogastrostomy, and jejunostomy	Well 17 months after operation	
7	Chinese	M	52	Lower end of esophagus and cardia of stomach	Squamous	Oct. 17, 1940, jejunostomy; Nov. 4, 1940, thoracicoabdominal resection, esophagogastrostomy, and partial hepatectomy	Died of mediastinal abscess, 18 days after operation	Part of left lobe of liver resected with the tumor because of inseparable adhesions. No residual tumor found on autopsy
8	Chinese	M	41	Lower end of esophagus and cardia of stomach	Squamous	Feb. 15, 1941, thoracicoabdominal resection, esophagogastrostomy, and jejunostomy.	Well 8 months after operation	Postoperative x-ray therapy was administered to the region of the anastomosis because the resection was too close to the tumor
9	German	M	62	Lower end of esophagus and cardia of stomach	Adenocarcinoma	Mar. 19, 1941, thoracicoabdominal resection, esophagogastrostomy, and jejunostomy	Died of heart disease 6 months after operation	Partial autopsy revealed no recurrence of tumor
10	Chinese	M	62	Lower end of esophagus and cardia of stomach	Squamous	July 7, 1941, thoracicoabdominal resection, esophagogastrostomy, jejunostomy and splenectomy	Well 3 months after operation	Spleen was removed because of injury to the splenic vein during the operation
11	Chinese	F	53	Lower end of esophagus	Squamous	Aug. 6, 1941, thoracicoabdominal resection, esophagogastrostomy, and jejunostomy	Well 1 month after operation	

*Five resections without anastomosis (Cases 1 to 5) were done; there were two operative deaths, one subsequent death from tuberculous pneumonia, and two survivals, six and four and one-half months, respectively, after operation. Six resections with anastomosis (Cases 6 to 11) were done; there were one operative death, one subsequent death from heart disease and four survivals, seventeen, eight, three, and one month, respectively, after operation.

that many other major intrathoracic operations are performed satisfactorily without such preparation, there seems to be little theoretical basis for its use, and we believe that this procedure may be omitted in the future.

ANESTHESIA

Many types of anesthesia have been used.[6] However, the choice of the anesthetic agent depends upon the facilities available and the preference of the surgeon. Most of our patients were operated upon under a mixture of nitrous oxide, oxygen, and ether administered with low-grade positive pressure, through a tightly fitted mask. In several cases, the operation for the most part was carried out under drop ether anesthesia. However, when a bilateral pneumothorax is developed following injury of the contralateral pleura, the employment of positive pressure breathing is imperative.

At the end of the operation, the lung should be reexpanded gradually by a moderate positive pressure or preferably by the removal of the residual air in the pleural cavity by aspiration. High positive pressure or strong suction should be avoided because of the danger of rupture of the alveoli of the lung. We emphasize this point because tension pneumothorax developed in two cases of our series in the early postoperative course. Apparently the sudden change of the intrapulmonary and intrapleural pressures during and after the operation was responsible for this serious complication.

THE OPERATIVE PROCEDURE

The choice of the operative procedures depends upon the location of the tumor.[3, 5, 6, 8] When the lesion is in the middle third of the esophagus, the thoracicocervical resection is indicated. For a tumor in the lower third of the esophagus or the cardia of the stomach, the thoracicoabdominal resection and esophagogastrostomy should be attempted. In one of our eleven cases (Case 1), a thoracicoabdominal resection and dorsal esophagostomy[9, 10] were done. The result was unsatisfactory because the patient could not take care of the esophagostomy opening in his back (Fig. 1). For this reason, we believe that this type of operation will not be recommended in the future. Four of our patients had thoracicocervical resection (Fig. 2), and six others had thoracicoabdominal resection and esophagogastrostomy (Fig. 3). The general plan and some of the technical details used by us in the latter two types of operation will be discussed.

1. Thoracicocervical Resection for Carcinoma of the Middle Portion of the Esophagus.—The thoracic esophagus may be approached from either side of the chest. The left-sided approach was used by us with satisfactory results in this group of cases. However, it is to be pointed

out that, in the four patients in whom we carried out this operation, the tumor was situated just below the arch of the aorta. In case the bulk of the tumor is immediately behind the aortic arch, we believe a right-sided approach with division of the major azygos vein will give a better exposure.[8, 11]

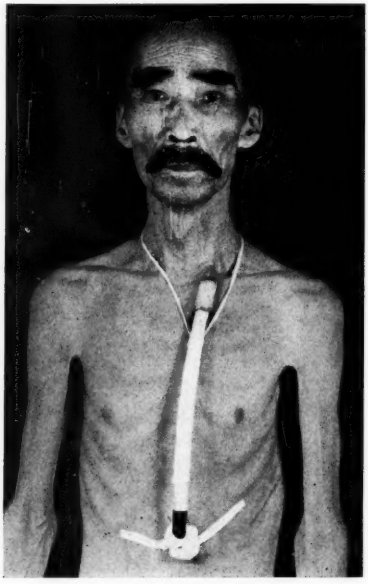
Fig. 1.—Case 1. Postoperative photograph of the patient following resection of a carcinoma of the cardio-esophageal junction and dorsal esophagostomy.

In the left-sided approach, the incision starts in the interscapular region at the level of the fourth rib coursing around the lower angle of the scapula and extending toward the costal margin. The pleural cavity is entered after resection of the entire length of the seventh rib or through the seventh intercostal space. The posterior ends of the two or three ribs above together with the intercostal bundles are divided. The esophagus is located between the descending aorta and the pericardium after the lung is retracted anteriorly. The exposure is facilitated by division of the pulmonary ligament. A careful examination of the tumor is carried out to determine its resectability. It is sometimes difficult to be certain about the extent of the tumor until it is partially mobilized. However, in the absence of fixation to the surrounding vital structures, a resection should be attempted.

The procedure we employed was the modified Torek operation as described by Garlock.[2, 3] There is no necessity for a description of the technique in this communication. We also agree with the latter author that the phrenic nerve should not be paralyzed in this type of operation.

A.

B.



C.

Fig. 2.—Case 2. Thoracicocervical resection of a carcinoma in the middle third of the esophagus. *A*, The preoperative roentgenogram; *B*, the surgical specimen; *C*, the postoperative photograph of the patient.

However, sometimes it may be necessary to enlarge the esophageal hiatus of the diaphragm to facilitate the closure of the lower stump of the esophagus.

In performing the cervical esophagostomy, we found that Carter's procedure[12] of dissecting the esophagus through the apex of the chest into the neck was a timesaving and satisfactory method. The cervical incision was closed without drainage. The esophageal stump was fixed to the infraclavicular incision loosely with interrupted silk sutures and was opened immediately. No infections of the cervical wounds or around the esophageal stumps were observed.

2. Thoracicoabdominal Resection and Esophagogastrostomy for Carcinoma of the Lower Third of the Esophagus or Cardia of the Stomach. —The operation is performed through the left pleural cavity. The incision begins in the lower part of the interscapular region going downward and anteriorly along the seventh rib extending into the left hypochondrium to the lateral border of the left rectus muscle. The pleural cavity is entered after resecting the entire length of the seventh rib or through the seventh intercostal space. The costal margin is divided through the cartilage, and the peritoneal cavity is exposed at the lower end of the incision. The pleural cavity and the upper abdomen is made into one operative field after incising the diaphragm from the esophageal hiatus to the periphery. No ill effects were observed following division of the costal margin in any of our cases. However, it is generally advisable to start with a shorter thoracic incision for exploration of the tumor and to complete the entire exposure when no contraindications to resection are found.

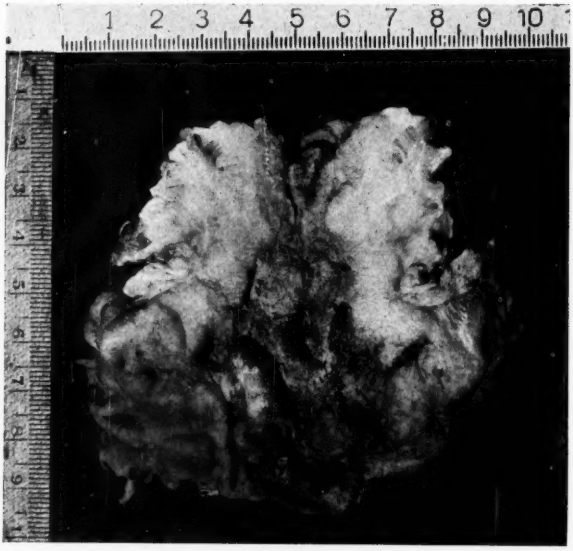
The technique of resection and the esophagogastric anastomosis used by us has been described previously,[6] being similar to that employed by Adams and Phemister.[4] In the mobilization of the tumor at the cardioesophageal junction, a normal margin of the diaphragm around the esophageal hiatus should be excised together with the tumor. In two of our cases, cancer cells were found in that part of the diaphragm on microscopic examination. The fact that sufficient lengths of the esophagus and the stomach are necessary for the anastomosis should not lead the surgeon to perform the resection too near the tumor. In one of our cases (Case 8, Fig. 3) the lines of resection were inadvertently placed only about one inch from the tumor at the time of the operation. Subsequent examination of the sections made from the esophageal end of the specimen revealed cancer cells. Apparently a much wider excision is desirable.

The esophagogastrostomy is performed in an end-to-side manner by the direct suture method. Satisfactory healing of the anastomosis took place in four of our six cases. All of these patients enjoyed normal food with no interference with swallowing. We believe the most important factor in the success of the anastomosis is the avoidance of tension

on the suture line. In order to accomplish this principle, the following points deserve emphasis:

(A) Thorough mobilization of the stomach into the chest. In doing so we divided the left gastric vessels in the gastrohepatic omentum and the short gastric vessels in the gastrosplenic ligament in all our cases and observed no interference with the blood supply of the stomach.

A.



B.

Fig. 3.—Case 8. Thoracicoabdominal resection of a carcinoma in the lower end of the esophagus and the cardia of the stomach and esophagogastrostomy. *A*, The preoperative roentgenogram; *B*, the surgical specimen.

(B) Anchorage of the lower end of the esophagus and the upper end of the stomach to the adjacent periosteum of the rib or vertebra as proposed by Carter, Stevenson, and Abbott.[13, 14]

(C) Paralyzing the diaphragm by crushing the phrenic nerve during the operation and suturing the diaphragm around the lowest portion of the stomach to support the weight of the latter organ.

(D) Decompression of the stomach through a nasal tube during the first three or four days.

(E) The patient is advised to avoid the act of swallowing, including that of saliva, during the first week after the operation. Feeding is given through the jejunostomy which is established at the time of the resection.

C. *D.*

Fig. 3.—Case 8. *C,* The postoperative roentgenogram showing the esophagogastrostomy; *D,* the postoperative photograph of the patient.

In both types of operation, during the dissection of the esophagus much care should be exercised not to open into the contralateral pleura on the other side of the mediastinum. Sometimes this has to be done intentionally because of direct tumor infiltration, as in our Cases 3 and 4. Even in the absence of tumor involvement, the contralateral mediastinal pleura may be torn easily during the blunt dissection of the esophagus. This happened in our Cases 2, 6, and 8. The resultant bilateral pneumothorax is usually accompanied by a marked drop in blood pressure and sometimes embarrassment of the respiration, in spite of the employment of positive pressure breathing. Four of our five

patients, in whom bilateral pneumothorax was so produced during the operation, developed serious intrathoracic complications.

Measures to prevent infection in the chest must be taken during the operation. This can be accomplished largely by mechanical means, such as protecting the pleural surfaces with pads, covering the divided esophageal end with a rubber sheath, and controlling the leakage of the esophageal and gastric contents with special clamps. The incised mediastinal pleura should be left open, and a moderate dose of sulfanilamide powder should be distributed in the mediastinum and the pleural cavity.

The question of drainage of the pleural cavity is still debatable in our minds. Although we employed closed drainage with a mild continuous suction in all of our cases, we were not convinced of its real value. The drainage usually ceased within forty-eight hours after the operation. Eleven in the two cases (Cases 2 and 4) in which tension pneumothorax developed the thoracostomy failed entirely to prevent or relieve such a complication, because the tube was walled off by adhesions.

POSTOPERATIVE COMPLICATIONS

Unfortunately, complications are frequent following resection of the esophagus. The following important ones were observed in this series of cases:

1. Mediastinal Abscess.—In one case (Case 7) this was secondary to leakage at the esophagogastric anastomosis following resection of an extensive tumor of the cardio-esophageal junction. The postoperative course seemed to be satisfactory for two weeks. The patient suddenly collapsed on the sixteenth day and died two days later. A large mediastinal abscess around the ruptured anastomosis was discovered at autopsy. The shadow of the abscess was shown in the postoperative roentgenograms of the chest, but unfortunately it was misinterpreted as the intrathoracic portion of the stomach. We were also misled by the complete absence of fever in this case.

2. Putrid Empyema and Esophagogastropleural Fistula.—These complications developed in Case 9, secondary to leakage of the esophagogastrostomy. The diagnosis was established by roentgenologic examinations two weeks after the operation. Drainage of the empyema improved the infection but failed to control the putrid odor. In spite of the jejunostomy feeding, the esophagogastropleural fistula persisted. A cervical esophagostomy[15] was performed more than two months later, after which, the empyema cavity rapidly diminished in size and the putrid odor disappeared. The patient was able to have liquid food by mouth (the esophagostomy was connected to the jejunostomy by a rubber tube) up to the time of his death, six months after the resection.

3. Lung Abscess and Empyema.—In Case 3 a large ulcerative tumor of the middle portion of the esophagus was resected. The field was

grossly contaminated by the rupture of the tumor during the operation, and the right pleura was opened because of direct tumor infiltration. The immediate postoperative course was satisfactory. However, a lung abscess developed in the superior division of the left lower lobe and was drained six weeks after the resection. A subsequent roentgenogram of the chest revealed fluid in the right pleural cavity associated with a slight rise of temperature. Aspiration proved the purulent nature of the fluid. The empyema as well as the abscess healed well after drainage. The delayed development and the almost silent nature of the empyema in this case is remarkable.

4. Bronchopneumonia.—Pneumonia developed in two cases. In Case 5, the infection was bilateral, and the patient succumbed to this complication three days after the operation. In Case 8 it involved only the right lower lobe, and the patient recovered following the usual treatment.

5. Tension Pneumothorax.—This condition was bilateral in Case 2 and unilateral on the right side in Case 4. Each patient had a thoracicocervical resection for a mid-esophageal carcinoma. The contralateral mediastinal pleura was opened during the operation in both cases, being accidental in Case 2 and due to tumor infiltration in Case 4.

The pneumothorax in Case 2 developed three days after operation. It was complete on the right side and partial on the left because of the adhesion of the lower portion of the left lung to the chest wall. Repeated aspirations of large amounts of air from each side of the chest only temporarily relieved the patient from dyspnea and cyanosis. An intercostal tube had to be inserted into the right pleural cavity three days later. Leakage of air stopped after twenty-four hours. The pneumothorax on the left side was left alone, and it persisted for several weeks. However, it caused very little inconvenience to the patient.

The patient in Case 4 had a more marked immediate reaction than the other cases. His condition improved until thirty hours after the operation, when a tension pneumothorax developed on the right side. He died a few hours later in spite of prompt aspiration of air and insertion of an intercostal tube. No definite source of the pneumothorax was found on post-mortem examination.

6. Infection of Chest Wall.—A localized abscess developed under the incision at the region of the costal margin in Case 6. The infection involved the underlying costal cartilage, but it healed spontaneously four weeks after drainage.

SUMMARY

Eleven cases of resection of the esophagus for carcinoma are reported. Three patients died in the immediate postoperative period; two patients succumbed to some other disease subsequently; and six others are living and well from one to seventeen months after the operation.

For carcinoma in the middle portion of the esophagus, a thoracicocervical resection with a preliminary gastrostomy is the operative procedure of choice. In tumors of the lower third of the esophagus and cardia of the stomach, a thoracicoabdominal resection and esophagogastrostomy with complementary jejunostomy is indicated. We prefer to carry out the latter operation in one stage. Some of the technical details in both types of the operation are discussed.

With careful preoperative selection and preparation of the patient, the operation is surprisingly well tolerated. Unfortunately, postoperative complications are common and most of them are serious. Timely recognition and proper management of these complications constitute a very important step toward the immediate success of the operation.

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PULMONARY FUNCTION AFTER PNEUMONECTOMY IN CHILDREN

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THE effect of pneumonectomy upon physical capacity in general and upon pulmonary and cardiocirculatory function in particular has been studied in dogs by Longacre, Carter, and their associates.[1, 2] They have shown clearly that age at the time of operation influences the subsequent behavior of dogs under conditions of physical stress. In addition, they have shown that age at the time of operation influences the subsequent pathologic findings in the lung remaining after pneumonectomy. Their observations are consistent with those of Bremer[3] and represent further confirmation of his earlier work on cats.

Longacre and his co-workers found that, when pneumonectomy was performed on puppies, the functional capacity under conditions of physical stress soon returned to normal. This surprising finding was associated with enlargement of the remaining lung and histologic evidences of growth, including increase in number and decrease in size of alveoli. When pneumonectomy was performed on adult dogs, however, the functional capacity was found to be markedly diminished after operation. Again the remaining lung was enlarged, but pathologic sections showed evidence of emphysema, including enlarged alveoli with broken, overdistended walls. Other dogs, on whom pneumonectomy was performed during the period of growth, showed an early return to normal function, followed some years later by moderate impairment. Pathologically the remaining lungs in these animals showed a mixed picture, interpreted to be the result of hyperplastic changes during the growth period followed by emphysematous changes in later years. It is of great interest to determine whether human beings show functional and pathologic changes after pneumonectomy which correspond to those observed in animals.

On the tuberculosis service at Bellevue Hospital various physiologic studies are being carried out following pneumonectomy in patients of all ages, and the functional characteristics are considered from the point

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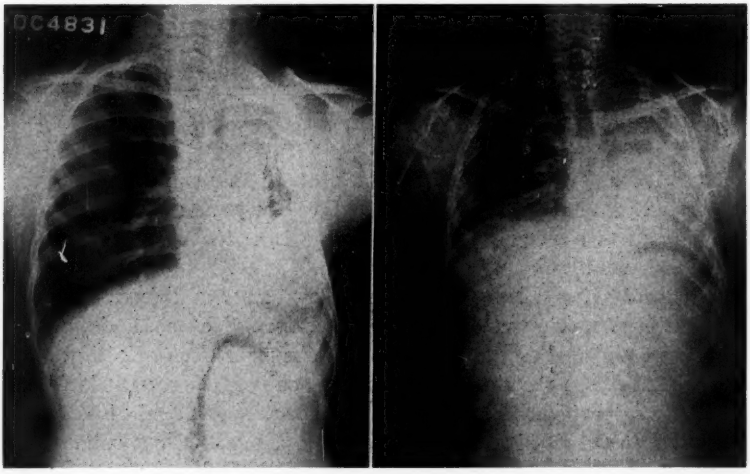
of view of their probable pathologic basis. The present report concerns three patients operated upon in childhood and studied while still in the period of growth.

MATERIAL FOR STUDY

Three children whose left lungs were removed in one or several stages for bronchiectasis or pulmonary suppuration will be discussed. Their ages were 9, 12, and 14 years at the time of study. Clinical histories can be summarized as follows:

CASE 1.—H. W. was born in 1931. At the age of 1 year she developed bronchopneumonia followed by persistent cough. After being in and out of various hospitals she was admitted to the pediatrics service at Bellevue Hospital in 1935. Bronchograms showed that she had extensive bronchiectasis involving both lobes of the left



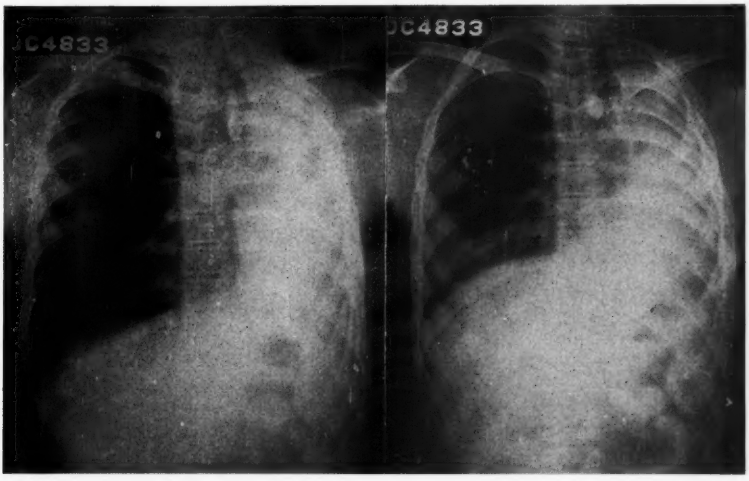
A. *B.*

Fig. 1.—Subject H. W. Physical characteristics, chief points in history and roentgenograms taken in deep inspiration and forced expiration. Note (1) trachea in the midline in expiration, slightly displaced toward left in inspiration, (2) excursion of right diaphragm, three rib interspaces, (3) motion of left diaphragm revealed by change in position of stomach air bubble. Age, 9 years; height, 134 cm.; weight, 33 kg.; s.a., 1.09 sq. m. Age at onset of disease, 1; lobectomy, 5; pneumonectomy, 6; final operation, 8. *A*, Inspiration; *B*, expiration.

lung. In October, 1936, the left lower lobe was removed with the expectation of removing the upper lobe after her recovery. During convalescence, however, she developed diphtheria and then measles, necessitating postponement of the removal of the upper lobe until October, 1937. Following this operation she made a good recovery and was discharged from the hospital in February, 1938, with the wound healed. After several months with little or no symptoms her cough returned and with it sputum and foul breath. Bronchograms showed pockets at the ends of open branch bronchi, and an attempt at closure was made by bronchoscopic means. This being unsuccessful, external drainage was performed through a thoracotomy wound in November, 1939. In due course the sputum stopped; drainage ceased; and the wound was

allowed to heal. Shortly after discharge, however, the symptoms recurred. In April, 1940, the thorax was opened and the stem bronchus was resected. From this she made a good recovery and has been entirely free of symptoms since. She attends school, plays in a normal manner with children of her age, and seems to be entirely healthy.

CASE 2.—J. L. was born March 16, 1929. He was admitted to Bellevue Hospital in May, 1935, for tonsillectomy because of chronic productive cough. The Mantoux test was positive, but repeated sputum examinations failed to show tubercle bacilli. Bronchograms showed bronchiectasis involving the entire left lung. After prolonged and unsuccessful attempts at relieving his condition by postural and bronchoscopic drainage and other medical means, he was transferred to the children's surgical service where pneumonectomy was performed in November, 1939. A Shenstone tourniquet was applied to the hilus of the left lung, and the lung was excised distal to it. Empyema followed, requiring rib resection for drainage three weeks later, but he nevertheless made a satisfactory recovery and was discharged from the hospital entirely healed in March, 1940. Since that time he has attended school regularly. He plays with the other boys of his age and does not limit his activities in any manner.



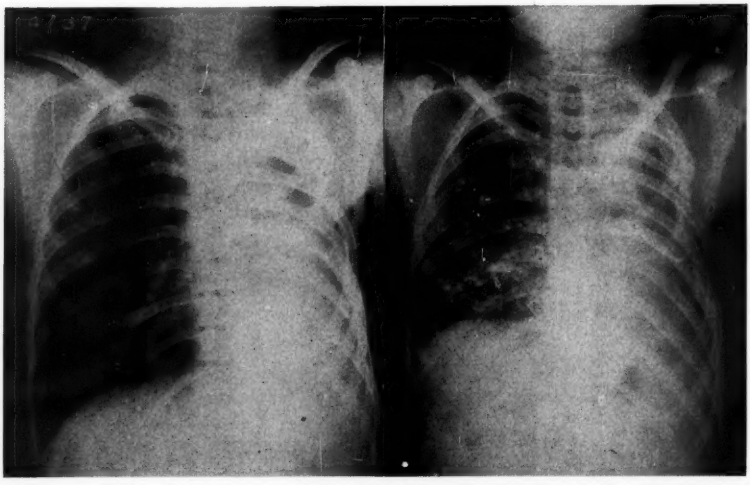
A. *B.*

Fig. 2.—Subject J. L. Physical characteristics, chief points in history and roentgenograms taken in deep inspiration and forced expiration. Note (1) trachea displaced to left of midline in expiration, further displaced in deep inspiration. (2) excursion of right diaphragm, one rib interspace, (3) very small motion of left diaphragm as revealed by position of the stomach's air bubble. Age, 12 years; height, 160 cm.; weight, 47 kg.; s.a., 1.46 sq. m. Age at onset of disease, 5; pneumonectomy, 10. *A*, Inspiration; *B*, expiration.

CASE 3.—R. G. was born Oct. 8, 1927. He developed a lung abscess after whooping cough in June, 1936, and was admitted to Bellevue Hospital on the pediatrics service in January, 1937. The lung abscess was drained in February, 1937, and, in September, 1937, the resulting bronchocutaneous fistula was closed with a muscle flap graft. Six weeks after healing, an upper respiratory infection reactivated the abscess. Removal of the involved left lung was decided upon, and in February, 1938, operation was performed. The abscess was found to involve both lobes. A Shenstone tourniquet was applied to the hilus, and the lung was removed distal to it.

Subsequent empyema caused him to have a stormy course, but eventually healing took place. A pneumothorax still remains, with a minute fistula communicating with the bronchial tree. Clinically he is now entirely well. He attends school and engages in the same strenuous exercises practiced by other boys of his age.

Roentgenograms of the lungs of the three patients are shown in Figs. 1, 2, and 3. These were taken in deep inspiration and in complete expiration in order to demonstrate the position and amplitude of motion of the ribs, diaphragms, and mediastinums. H. W. shows a larger than normal lung in inspiration, due mainly to displacement of the mediastinum and lowering of the diaphragm. In expiration, however, the trachea returns to the midline and the right diaphragm elevates well, so that, in spite of the fact that the heart is still displaced to the left, it appears that the expiratory lung volume is approximately normal. Essentially these observations apply to R. G. In the case of J. L., on the other hand, not only the inspiratory volume but also the expiratory volume appears definitely larger than it would be in the normal. The trachea and heart remain considerably displaced to the left on complete expiration, and the diaphragmatic excursion is less than in the other two cases.



A. *B.*

Fig. 3.—Subject R. G. Physical characteristics, chief points in history and roentgenograms taken in deep inspiration and complete expiration. Note (1) trachea in midline in expiration, hardly visible, but slightly to the left in inspiration, (2) excursion of the right diaphragm about two rib interspaces, (3) large air pocket in left chest, (4) residual lipiodol remaining after bronchogram performed a few days before. Age, 14 years; height, 165 cm.; weight, 48 kg.; s.a., 1.51 sq. m. Age at onset of disease, 9; drainage, 10; pneumonectomy, 11. *A*, Inspiration; *B*, expiration.

METHOD OF STUDY

The following measurements were made:

A. Lung volumes and subdivisions.

B. Maximum breathing capacity.

C. Ventilation, breathing reserve, and respiratory gas exchange under basal conditions, during moderate exercise, during a five-minute period

of recovery following moderate exercise, and finally, during the last minute of an exhaustive type of exercise, lasting in most instances four minutes. The state of respiratory gases in the arterial blood was studied at rest, immediately after the completion of moderate exercise, and again immediately after completion of exhaustive exercise. In all instances the subjects were breathing room air.

Fifteen normal children were studied for comparison with the three patients who had undergone pneumonectomy. The normal subjects were chosen so as to fall into three groups of five, with the members of each group corresponding in age, height, weight, and body surface area to one of the patients. The physical characteristics of patients and normal children are shown in Table I.

TABLE I

PHYSICAL CHARACTERISTICS

(of Three Children After Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects)

	AGE (YEARS)	HEIGHT (CM.)	WEIGHT (KG.)	BODY SURFACE AREA (SQ. M.)
Group I				
Normals				
Mean	10.0	137.5	32.1	1.11
Range	8-13	129-147	27.0-35.5	1.01-1.22
H. W.	9	133.0	32.5	1.08
Group II				
Normals				
Mean	12.1	150.1	45.6	1.38
Range	11-13	146-155	43.0-47.5	1.34-1.44
J. L.	11.5	157.5	45.5	1.43
Group III				
Normals				
Mean	14.4	161.0	49.9	1.50
Range	14-15	152-172	42.0-56.0	1.34-1.65
R. G.	14	163.0	45.0	1.46

TECHNIQUE

The techniques used for measurement of lung volumes, maximum breathing capacity, ventilation and gas exchange at rest, during moderate exercise and during the recovery period following it, were the same with minor changes as those described elsewhere.[4] Identical tests were used for patients and normal subjects except that no arterial blood was taken on the normal subjects. Residual air was measured by the open circuit method.[5] The figures for nitrogen excretion, which are required in the calculation, were based on body surface area.[9] Moderate exercise consisted in stepping up and down on a stool 20 cm. high thirty times in one minute. Exhaustive exercise consisted in stepping or running up and down on this same stool at the rate of about forty steps per minute for four minutes. Variations, depending upon the endurance of the subject, will be discussed later. Expired air was collected and measured during the last minute of exhaustive exercise and analyzed for oxygen and carbon dioxide. The amount of exercise approximated climbing from the ground floor to the roof of a nine-story building and returning in four minutes. Lacking a treadmill, this was the

most severe type of exercise that could be devised, but it is acknowledged that, due to the high degree of muscular coordination required, it probably did not lead to as complete exhaustion as exercise performed on the treadmill.[6]

RESULTS

I. LUNG VOLUMES

Measurements of lung volumes are tabulated in Table II and are represented graphically in Chart I. Fifty-five per cent of the values observed for both lungs in the normal subjects is taken as an approximation of the values for the right lungs alone.

(a) *Total Capacity.*—The total capacities of the single remaining lungs of the three children studied after pneumonectomy were smaller than those of both lungs of the normal subjects, but larger than those of their right lungs alone.

(b) *Residual Air.*—The volumes of air remaining in the lungs of H. W. and R. G. after a complete expiration were identical to those remaining in the right lungs of their control groups. In contrast, the volume of residual air of J. L. was as large as that in both lungs of the normal subjects, or almost twice as large as that in their right lungs alone.

(c) *Reserve Air.*—In H. W. the volume of air displaced during a complete expiration corresponded to the volume displaced in the right lungs of her control group, but in J. L. and R. G. it was almost as large as the volumes displaced by two lungs of their controls.

(d) *Complemental Air (Including Tidal Air).*—The complemental air volumes in the remaining right lungs of H. W. and R. G. were distinctly greater than the corresponding volumes in the right lungs of the normal subjects, while J. L.'s complemental air was only slightly greater than that in the right lungs of his control group.

(e) *Vital Capacity.*—In all cases, the vital capacities were larger than the assumed vital capacities of the right lungs of their controls though in different degrees. H. W. and R. G. had vital capacities 31 per cent larger than the vital capacities of the right lungs of the control groups, whereas J. L.'s vital capacity was 26 per cent larger.

In summary, compared to the right lungs of the control group, the remaining lung of H. W. was no larger in forced expiration and only moderately larger in deep inspiration; that of J. L. was the size of both lungs of the normal subjects in forced expiration and was markedly larger than their right lungs alone in deep inspiration. Finally, the lung of R. G. was the same size as the right lungs of the normal subjects in forced expiration and was enlarged in the same proportion as H. W.'s in deep inspiration.

These lung volume measurements are consistent with the information obtained from the study of the roentgenograms taken in deep inspira-

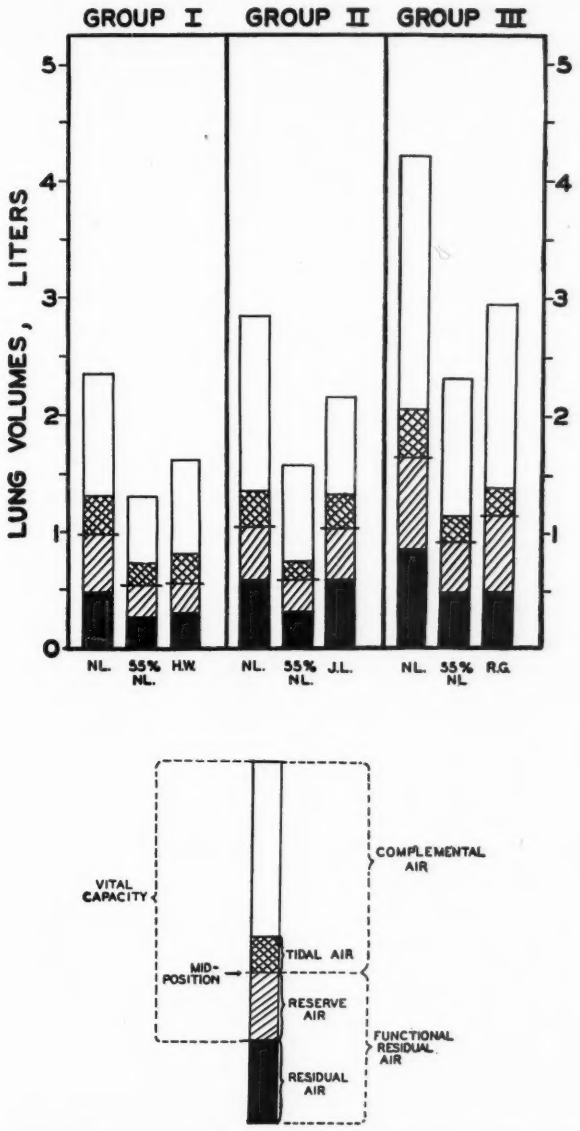


Chart I.—Lung volumes and subdivisions. In each group, the blocks to the left represent the average values in the normal children; the blocks in the center, the assumed values for the right lung of the normal children; the blocks to the right, the observed values in the subjects studied after pneumonectomy. Key to the chart is in the inset.

TABLE II

LUNG VOLUMES*

(of Three Children After Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects)

	TOTAL CAPACITY (L.)	VITAL CAPACITY (L.)	RESIDUAL AIR (L.)	$\frac{\text{R.A.}}{\text{T.C.}} \times 100$ (%)	RESERVE AIR (L.)	COMPLEMENTAL AIR (L.)	TIDAL AIR (L.)
Group I							
Normals							
Mean	2.37	1.89	0.48†	20.4	0.50	1.38	0.34
Range		1.61-2.02			0.37-0.56	1.24-1.49	0.23-0.60
55% normal	1.30	1.04	0.27	20.4	0.28	0.76	0.19
H. W.	1.61	1.30	0.29	17.9	0.26	1.04	0.27
Group II							
Normals							
Mean	2.86	2.28	0.58	20.4	0.46	1.81	0.32
Range		1.72-2.76			0.24-0.54	1.49-2.22	0.24-0.43
55% normal	1.57	1.25	0.32	20.4	0.26	1.00	0.18
J. L.	2.16	1.58	0.58	26.7	0.43	1.15	0.29
Group III							
Normals							
Mean	4.21	3.36	0.86	20.4	0.79	2.57	0.42
Range		2.82-3.98			0.61-1.05	2.18-2.93	0.33-0.49
55% normal	2.32	1.85	0.47	20.4	0.43	1.41	0.23
R. G.	2.94	2.47	0.47	16.0	0.67	1.80	0.25

*Saturated gas at 37° C. and prevailing barometric pressure.

†Residual air volumes for controls calculated as 20.4 per cent of total capacity.

tion and forced expiration. Since inspiratory volume corresponds to total capacity and expiratory volume to residual air, the roentgenograms provide, at least in part, visual explanation of the different abnormalities in lung volumes. This is of particular interest in the case of J. L., whose residual air as determined was proportionally higher than in the other patients. His roentgenograms show that the remaining lung can never attain a normal expiratory volume because of the marked displacement of the mediastinum. His lung is, therefore, distended more than the normal amount even in forced expiration. Furthermore, the increase in the displacement of the mediastinum to the left in inspiration suggests that the expansion of the left hemithorax draws the mediastinum to that side and causes the right lung to expand into the left chest. The over-all size and shape of this lung thus appear to be determined primarily by the size and shape of the space existing within the thorax.

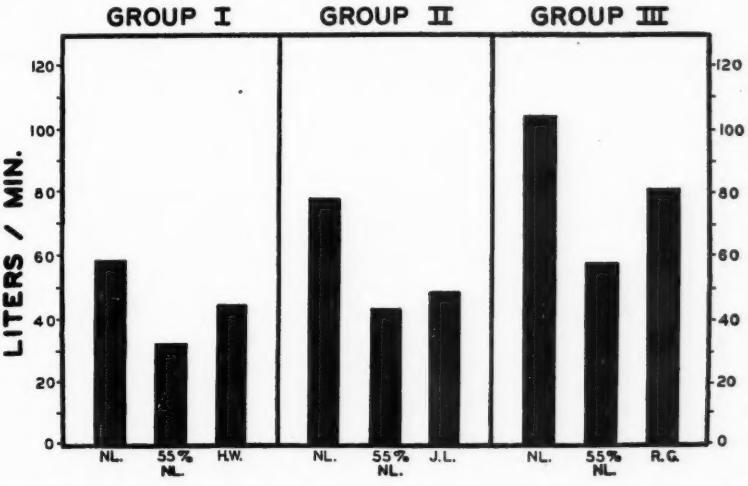


Chart II.—Maximum breathing capacity. In each group, the block to the left represents the average value in the normal children; the block in the middle, 55 per cent of this average value; and the block to the right, the value observed in the subjects studied after pneumonectomy.

II. MAXIMUM BREATHING CAPACITY

The measurements of maximum breathing capacity are tabulated in Table IV and are represented graphically in Chart II. The maximum breathing capacities of H. W. and R. G. represented respectively 76 and 78 per cent of the maximum breathing capacities of their controls; that of J. L. was only 62 per cent of his control. The potentiality of the chest bellows of J. L. for displacing large volumes of air per unit of time was thus somewhat less, compared to his controls, than in the

other cases. It is suggested that the permanent overdistention of the remaining lung of J. L. may be related to the decreased efficiency of his chest bellows.

The relation existing between vital capacity and maximum breathing capacity in the fifteen normal children and the three children studied after pneumonectomy is illustrated by a scatter diagram in Chart III. This shows a linear relationship and suggests a high degree of correlation, in contradistinction to what is observed in normal adults.[7]

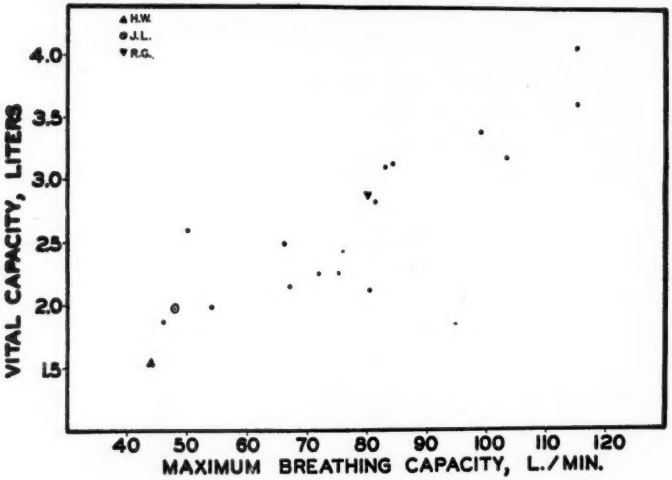


Chart III.—Scatter diagram relating vital capacity and maximum breathing capacity in fifteen normal children and three subjects after pneumonectomy.

III. VENTILATION, BREATHING RESERVE, AND RESPIRATORY GAS EXCHANGE IN VARIOUS STATES OF PHYSICAL ACTIVITY

A. *Basal State.*—The measurements obtained in this state are tabulated in Tables III, IV, V, and VIII and in Charts IV, V, and VI.

1. *Ventilation in liters per square meter body surface area per minute.*—There was no important difference between the volumes of air ventilated in the basal state by the children after pneumonectomy and by the corresponding groups of normal subjects. The tidal air volumes in the three children investigated were somewhat smaller than in their control groups, and conversely the respiratory rates were somewhat greater.

2. *Breathing Reserve.*—Because of the smaller maximum breathing capacities, the breathing reserves at rest were less for the patients than for the control groups.

3. *Oxygen Intake.*—The resting oxygen intake, from which the basal metabolism is calculated, corresponded in the three control groups to

TABLE III

VENTILATION*

(In Basal State, Moderate Exercise, and During Five Minutes of Recovery From Moderate Exercise, of Three Children After Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects)

	BASAL STATE (L./SQ. M/MIN.)	MODERATE EXERCISE (L./SQ. M/MIN.)	RECOVERY FROM MODERATE EXERCISE (L./SQ. M/MIN.)				
			1ST MIN.	2ND MIN.	3RD MIN.	4TH MIN.	5TH MIN.
Group I							
Normals							
Mean	4.93	11.27	12.5	6.9	5.8	6.3	5.3
Range	4.01-5.59	8.72-12.57	10.7-13.5	5.2-8.9	5.0-6.4	5.8-6.7	4.0-6.2
H. W.	4.22	12.50	9.5	9.7	9.8	9.3	10.0
Group II							
Normals							
Mean	4.41	11.33	10.9	7.2	5.8	5.0	4.8
Range	3.40-5.04	8.66-13.59	10.0-11.3	6.0-9.1	5.0-7.7	3.7-6.4	4.2-5.8
J. L.	3.66	12.02	11.8	7.6	6.9	6.6	5.6
Group III							
Normals							
Mean	4.01	10.10	11.4	7.6	6.5	5.4	4.8
Range	3.79-4.38	5.64-12.45	10.0-14.7	6.5-9.3	5.2-8.1	4.8-5.7	3.3-5.7
R. G.	4.50	12.40	12.1	8.8	6.9	6.4	6.1

*Saturated gas at 37° C. and prevailing barometric pressure.

TABLE IV

MAXIMUM BREATHING CAPACITY. BREATHING RESERVE

(In Basal State, Moderate Exercise, and During Five Minutes of Recovery From Moderate Exercise, of Three Children After Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects)

	MAX. BREATHING CAPACITY STANDING L./MIN.	BREATHING RESERVE / MAXIMUM BREATHING CAPACITY × 100						
		BASAL STATE	MODERATE EXERCISE	RECOVERY FROM MODERATE EXERCISE				
				1ST MIN.	2ND MIN.	3RD MIN.	4TH MIN.	5TH MIN.
Group I								
Normals								
Mean	57.9	89.3	78.0	73.1	86.5	87.6	86.4	88.5
Range	46.1-72.2	84.8-92.2	72.0-83.5	63.0-78.9	75.6-91.3	86.2-89.2	82.6-89.7	86.2-93.2
H. W.	44.0	85.6	69.4	67.8	67.2	66.9	68.8	66.2
Group II								
Normals								
Mean	77.4	91.5	79.9	78.7	86.1	88.8	90.2	90.7
Range	66.2-84.2	90.3-92.6	76.6-82.6	73.6-82.2	83.0-88.8	86.8-90.6	87.3-92.6	89.2-92.2
J. L.	48.1	88.0	54.3	61.0	75.0	77.0	78.1	81.5
Group III								
Normals								
Mean	103.0	93.0	85.2	80.3	86.8	88.9	90.7	91.7
Range	82.6-115.4	91.5-93.8	79.8-91.5	76.6-84.7	85.2-89.3	87.1-91.4	88.8-92.1	88.0-93.9
R. G.	80.0	89.8	77.4	69.2	77.6	82.6	83.7	84.4

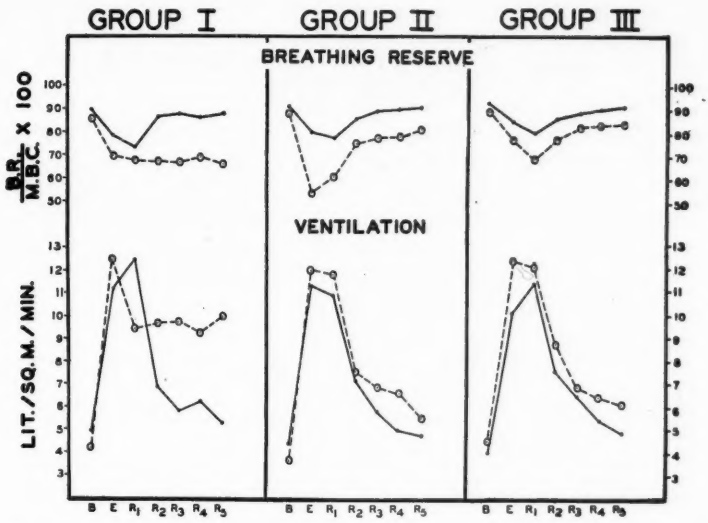


Chart IV.—Ventilation and breathing reserve expressed as ratio $\frac{\text{breathing reserve}}{\text{maximum breathing capacity}} \times 100$, during quiet breathing, moderate exercise, and recovery from moderate exercise. Solid dots joined by straight line represent the mean value in each group of normal children. Open circles joined by broken lines represent the values in each of the three subjects studied after pneumonectomy.

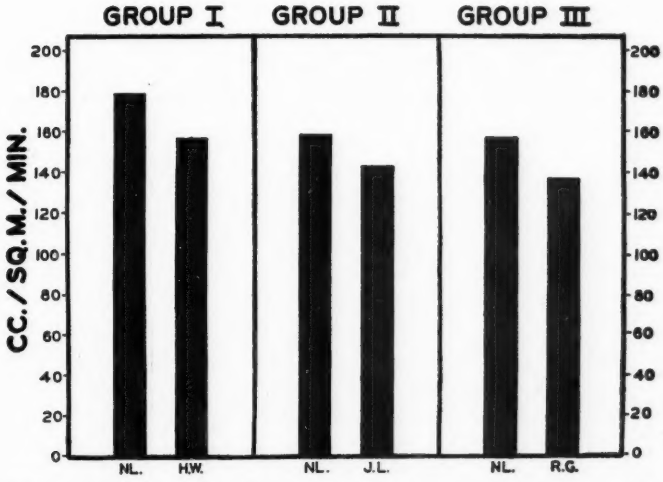


Chart V.—Oxygen consumption under basal metabolic conditions. In each group the solid block to the left represents the mean value in the normal children; the solid block to the right, the value observed in the subjects studied after pneumonectomy.

TABLE V

O_2 INTAKE, CO_2 OUTPUT

(in Basal State, Moderate Exercise, and During Five Minutes of Recovery From Moderate Exercise),

AND O_2 DEBT

(of Three Children After Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects)

	O_2 INTAKE*				CO_2 OUTPUT*		
	BASAL (C.C./SQ. M/MIN.)	MODERATE EXERCISE (C.C./SQ. M/MIN.)	5 MIN. RECOVERY (C.C./SQ. M/MIN.)	O_2 DEBT†	BASAL (C.C./SQ. M/MIN.)	MODERATE EXERCISE (C.C./SQ. M/MIN.)	5 MIN. RECOVERY (C.C./SQ. M/MIN.)
Group I							
Normals							
Mean	178	503	1320	48	144	337	1171
Range	160-192	457-559	1229-1411	47-54	133-159	270-409	1042-1215
H. W.	156	507	1424	83	124	349	1330
Group II							
Normals							
Mean	158	581	1311	66	127	356	1130
Range	138-179	524-614	1247-1389	55-81	107-151	297-392	1111-1178
J. L.	143	540	1503	110	112	383	1402
Group III							
Normals							
Mean	157	529	1359	73	126	321	1181
Range	148-164	412-600	1269-1489	72-82	121-132	216-383	1071-1348
R. G.	137	544	1436	110	121	420	1551

*Dry gas at 0° C. and 760 mm. Hg.

$$\dagger O_2 \text{ Debt} = \frac{\left[\begin{matrix}O_2 \text{ consumption during} \\ 5 \text{ min. of recovery}\end{matrix}\right] - \left[\left\{\begin{matrix}O_2 \text{ consumption per} \\ \text{minute at rest}\end{matrix}\right\} \times 5\right]}{(O_2 \text{ consumption per minute at rest}) \times 5} \times 100$$

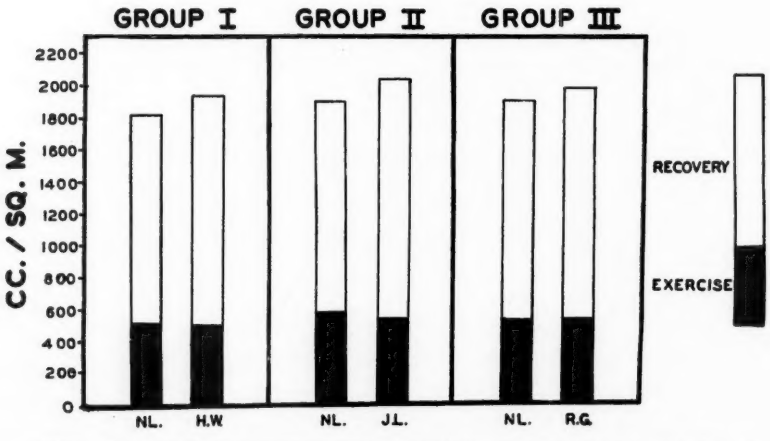


Chart VI.—Oxygen consumption during moderate exercise and five minutes of recovery following moderate exercise. Key is in the inset. In each group the blocks to the left represent the mean value in the normal children; the blocks to the right, the observed value in the children studied after pneumonectomy.

values obtained by Robinson in normal children of the same age.[6] The similarity of these figures obtained in separate studies adds importance to the finding that all three children after pneumonectomy had smaller volumes of oxygen intake than their controls. The reason for this is not clear, although one might assume that the removal of an organ as active physiologically as the lung might explain the decrease in oxygen intake, since the body surface area to which the oxygen intake is related remains unchanged.

4. *Oxygen Saturation of Arterial Blood.*—In all three cases the percentage of oxyhemoglobin was within normal limits.

In summary, the only significant finding under basal conditions was the small reduction in the rate of oxygen intake.

B. *Moderate Exercise.*—The tabulation and graphic representation of results are found in Tables III, IV, V, and VIII and in Charts IV, V, and VI.

1. *Ventilation.*—The rates of ventilation during the performance of moderate exercise were somewhat larger in the three cases studied than the corresponding average values for the controls, although the figures obtained for the patients were well within the range of variation of the normal children.

2. *Breathing Reserve.*—Because of the smaller maximum breathing capacities, the breathing reserves were more encroached upon than in the control groups. In J. L. the ratio $\frac{\text{B. R.}}{\text{M. B. C.}} \times 100$ dropped below the threshold of dyspnea.[4]

3. *Oxygen Intake and Carbon Dioxide Output.*—The rates of oxygen intake were remarkably similar to those of the control groups. Due to the somewhat larger amounts of ventilation, the rates of carbon dioxide output were somewhat higher.

In summary, the only significant findings were reduced breathing reserves, which in one case was within the limits where dyspnea is observed.

C. *Recovery From Moderate Exercise.*—Tables and charts are the same as in the preceding section.

1. *Ventilation.*—In all three cases, during each of the five minutes of the recovery period, the amounts of ventilation were greater than the average corresponding values for the control groups, with the single exception of the first minute of recovery in H. W. In this case, however, the ventilation persisted at a high level during the remaining four minutes.

2. *Breathing Reserve.*—The larger amounts of ventilation combined with smaller maximum breathing capacities in the three children ex-

plain the smaller breathing reserves during the period of recovery. J. L. was slightly dyspneic during the first thirty seconds of the recovery period.

3. *Oxygen Intake and Carbon Dioxide Output.*—In keeping with the larger ventilation, the total oxygen intake and especially the total carbon dioxide output were somewhat larger in the three children than the average corresponding values for the control groups. These values were beyond the upper limit of the range of variations, except in the case of R. G.

4. *Oxygen Debt.*—The oxygen debt, as expressed by the ratio

$$\frac{O_2 \text{ intake during 5 min. recovery} - (O_2 \text{ intake/min. at rest} \times 5)}{O_2 \text{ intake/min. at rest} \times 5} \times 100$$

was somewhat larger in the three children investigated than in their control groups.

5. *Oxygen Saturation of Arterial Blood.*—The percentage of oxyhemoglobin in the arterial blood withdrawn immediately after exercise was normal in all three cases.

In the attempt to account for the increased ventilation, oxygen intake, carbon dioxide output, and oxygen debt observed during the recovery period in the three children three hypotheses may be made:

(a) Oxygen utilization in the tissues during exercise is inefficient, so that more oxygen is required for the same amount of work than in the normal subjects.

(b) There is supplemental and ineffectual exertion increasing the oxygen requirement of the children with one lung above those of the children with two.

(c) Reflex stimuli arising from the distended lung, the displaced heart or the distorted great vessels cause hyperventilation and temporary oxygen intake exceeding the needs of the tissues.

The first hypothesis will be fairly conclusively answered by the results of exhaustive exercise. With regard to the second hypothesis, it is suggested that the expansion and contraction of the side of the chest in which pneumonectomy was performed is inefficient in bringing about ventilation of the remaining lung on the other side. This inefficient muscular activity may be considered as supplemental exertion, since, on this account, the total work done to accomplish a given amount of ventilation must be greater than in the normal subject. The third hypothesis is not unreasonable but lacks the support of further data.

D. *Exhaustive Exercise.*—The results are tabulated in Tables VI, VII, and VIII and are represented graphically in Chart VII.

1. *Number of Steps and Duration of Exercise.*—In Group I the number of steps up and down during four minutes was on an average 146.

TABLE VI

VENTILATION, TIDAL AIR, AND BREATHING RESERVE

(During the Fourth Minute of Exhausting Exercise of Three Children With Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects*)

	VENTILATION† (L./SQ. M/MIN.)	TIDAL AIR† (C.C.)	$\frac{\text{TIDAL AIR}}{\text{VITAL CAPACITY}} \times 100$	$\frac{\text{BREATHING RESERVE}}{\text{MAX. BREATH. CAPACITY}} \times 100$
Group I				
Normals				
Mean	27.5	713	32.1	46.3
Range	21.5-34.9	650-800	27.3-36.8	34.3-59.8
H. W.	29.1	695	49.3	21.0
Group II				
Normals				
Mean	29.2	954	38.1	47.9
Range	25.7-32.0	870-1160	30.9-42.2	42.8-53.9
J. L.	27.6	990	51.5	24.0
Group III				
Normals				
Mean	37.0	1293	37.5	45.8
Range	32.8-39.5	1140-1480	35.5-40.5	37.9-52.2
R. G.	30.2	1200	43.5	45.8

*For 1 normal in Group I and for Patient J. L. and 2 normals in Group II the figures refer to the third minute of exhausting exercise. These children were unable to continue for the fourth minute.

†Saturated gas at 37° C. and prevailing barometric pressure.

TABLE VII

O_2 INTAKE, CO_2 OUTPUT, AND RESPIRATORY QUOTIENT

(During the Fourth Minute of Exhausting Exercise of Three Children With Left Pneumonectomy and of Three Corresponding Groups of Five Normal Subjects*)

	O_2 INTAKE†			CO_2 OUTPUT†		
	(C.C./SQ. M./MIN.)	(C.C./KG. /MIN.)	(C.C./LITER VENT.)	(C.C./SQ. M./MIN.)	(C.C./LITER VENT.)	R.Q.
Group I						
Normals						
Mean	953	32.5	40.8	840	35.6	0.882
Range	804-1064	29.8-37.5	33.6-45.6	663-1051	30.5-40.9	0.706-1.05
H. W.	1043	34.8	42.2	974	39.4	0.934
Group II						
Normals						
Mean	1146	34.6	45.8	1070	42.7	0.933
Range	1075-1267	32.8-38.4	41.9-49.0	958-1137	39.5-48.4	0.876-0.988
J. L.	1190	35.7	49.5	1250	52.0	1.05
Group III						
Normals						
Mean	1371	41.5	42.9	1318	41.3	0.967
Range	1220-1515	35.3-48.4	39.3-45.4	1224-1372	39.1-42.9	0.901-1.08
R. G.	1217	37.4	46.1	1262	48.1	1.03

*See note at foot of Table VI.

†Dry gas at 0° C. and 760 mm. Hg.

TABLE VIII

ARTERIAL BLOOD

(of Three Patients After Left Pneumonectomy in Basal State, in Early Recovery From Moderate Exercise, and in Early Recovery From Exhausting Exercise)

PATIENT	STATE	CO_2 (VOLS. %)	HGB. O_2 SAT. (%)	TOTAL HGB. (GM.)
H. W.	Basal	46.9	95.7	13.3
	Early recovery from moderate exercise	45.1	97.8	
	Early recovery from exhausting exercise	44.0	98.0	
J. L.	Basal	51.1	95.3	13.0
	Early recovery from moderate exercise	---	---	
	Early recovery from exhausting exercise	51.8	92.4	
R. G.	Basal	47.9	92.6	13.4
	Early recovery from moderate exercise	48.2	92.8	
	Early recovery from exhausting exercise	47.6	96.6	

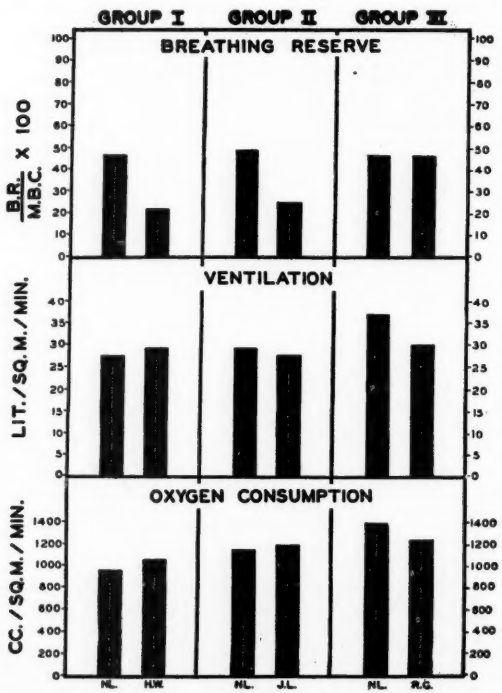


Chart VII.—Oxygen consumption, ventilation, and breathing reserve expressed as the ratio $\frac{\text{breathing reserve}}{\text{maximum breathing capacity}} \times 100$ during the last minute of the exhaustive exercise. In each group, the blocks to the left represent the mean value in the normal children; the blocks to the right, the observed value in the subjects studied after pneumonectomy.

H. W. exceeded this by taking 160 steps. In Group II the average number of steps climbed in four minutes was 157, but J. L. was able to continue for only three minutes. During this time he climbed 138 steps, at a rate which, if maintained during the fourth minute, would have led to a total of 184 steps. In Group III the average number of steps was 177. The performance of R. G. was carried through four minutes and amounted to 150 steps.

2. *Ventilation.*—In H. W. and J. L. the volumes of air ventilated were well within the range observed in their control groups. In R. G. the volume was smaller.

3. *Tidal Air.*—The volume of each breath during the last minute of exercise was almost identical in the patients with one lung and in the controls with two. Obviously the patients utilized a greater proportion of their vital capacity.

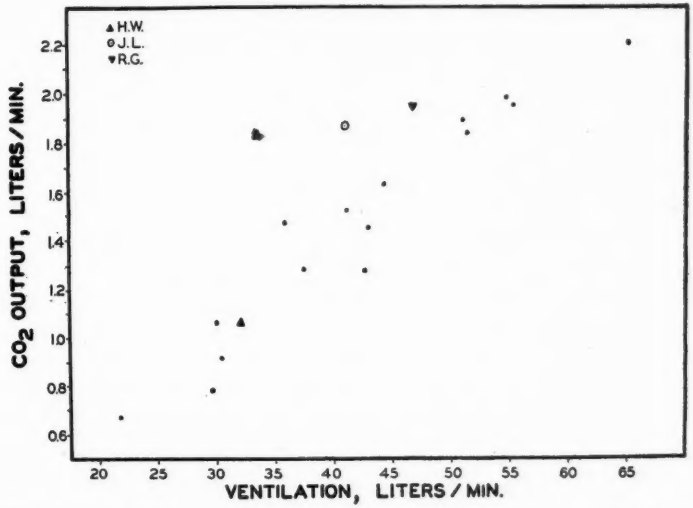


Chart VIII.—Scatter diagram showing the relation between carbon dioxide output and ventilation during the last minute after an exhausting exercise in fifteen normal children and three subjects after pneumonectomy. Note the straight relationship and the small scatter.

4. *Breathing Reserve.*—J. L. encroached upon his breathing reserve almost as much as H. W., who exercised for one minute longer. Whether the diminished breathing reserve and the resulting extreme dyspnea forced J. L. to stop after three minutes cannot be said. R. G. did somewhat less work than H. W., but, since his maximum breathing capacity was proportionally larger than his increase in ventilation, he encroached much less upon his breathing reserve. It is a striking fact that the normal children used only slightly more than half of their maximum

breathing capacities during the last minute of exhausting exercise. Two of the patients used a larger proportion of their maximum breathing capacities, but there still remained small breathing reserves. The limiting factor in performing exhaustive exercise was therefore probably not inability to ventilate adequately.

5. *Oxygen Intake, Carbon Dioxide Output and Respiratory Quotient.*—It has been shown by Robinson[6] that during the performance of exhaustive exercise the oxygen intake reaches a maximum during the second minute while the carbon dioxide output reaches a maximum during the third minute. The respiratory quotient obviously reaches its peak along with the carbon dioxide. The high respiratory quotients obtained during the last minute of exhausting exercise on all the children here studied, therefore, provide evidence that a relatively steady state had been reached at this time. The three children who had undergone pneumonectomy showed values for oxygen intake and carbon dioxide output which very closely corresponded to the normals. Since the amounts of ventilation tended to be slightly smaller the amounts of oxygen intake and carbon dioxide output per liter of ventilation were a little larger than in the normal subjects. The efficiency of gas exchange was thus excellent.

6. *Oxygen Saturation of Arterial Blood.*—The arterial blood withdrawn shortly after the cessation of the exhaustive exercise was normally saturated in all three subjects.

In summary, during the last minute of exhausting exercise, the ventilation, oxygen intake, and carbon dioxide output of the patients who had undergone pneumonectomy corresponded closely to the values for normal subjects. In two of the three patients the breathing reserve was encroached upon more than in the normals. All of the patients showed high efficiency of gas exchange.

DISCUSSION

In comparing the results of pneumonectomy in children and in puppies, one sees striking similarity in one major respect. When studied while still in the period of growth, both are able to perform strenuous exercise as well as normal subjects. There are differences, however, which deserve mention.

1. In puppies the period of adaptation to the removal of one lung begins at the time of operation, while in children the period of adaptation may conceivably have started with the onset of disease.

2. In puppies the remaining lung was free of disease at the time of operation, while in the children the remaining lung may have been previously damaged by repeated small bronchogenic spreads from the suppurative process.

3. In puppies, with narrow chests and mobile mediastinums, the remaining lung occupies the entire thorax. In the three children studied this situation was approached in one case (J. L.), but in the other two subsequent operative procedures resulted in reduced mobility of the mediastinum. In neither of these did the remaining lung increase its expiratory volume.

Four points regarding lung volumes and gas exchange are of special interest and apply equally to dogs and human beings.

1. When only dilution of respiratory gases is considered, the larger the tidal air and the smaller the functional residual air, the more efficient is the mixing of gases in the alveoli. Actually, vital capacity is found to be larger and functional residual air smaller when the lung is not pulled into the opposite chest.

2. Dead space in the bronchial tree is reduced, and a larger proportion of tidal air becomes effective following pneumonectomy provided the total volume of tidal air is not reduced.

3. Tidal air is possibly better distributed to ordinarily poorly ventilated alveoli, particularly around the hilum and at the apex, by expansion of the lung toward the opposite side.

4. Since more blood circulated through the remaining lung after pneumonectomy, the functional diffusing surface is either increased in area by increase in the number of capillaries or increased in efficiency by the passage of more blood through previously existing capillaries. The efficiency of exchange of respiratory gases between capillaries and alveoli is therefore probably increased. The area of functional diffusing surface bears no relation to functional residual air volume but is determined by the total area of pulmonary capillary walls which are in contact with alveoli.

Hyperplasia of alveoli following pneumonectomy, although demonstrated in growing dogs and cats, remains unproved in children. While hyperplasia in itself would be expected to lead to increased efficiency, the studies of Longacre and his associates show that even those dogs which develop hyperplasia during the growing period later develop emphysema.

Ventilation stands out as the chief respect in which the three patients were inferior to the normal subjects. Their breathing reserves were lower. However, even in exhausting exercise their reserves were not completely used up, showing that ventilatory capacity was still adequate for the most extreme demands.

The performance of two of the children following pneumonectomy was better than that of the third. Anatomically, the children who performed better showed lungs which were less distended than that of the child whose performance was poorer. On the basis of this evidence it is

suggested that overdistention of the lung following pneumonectomy is undesirable[8] and that measures designed to prevent marked displacement of the mediastinum should be considered. The type of measures and the time at which they should be undertaken are individual problems and must depend upon the age of the patient and the anatomic conditions developing after pneumonectomy.

SUMMARY AND CONCLUSIONS

1. Pulmonary function has been studied in three children after pneumonectomy from one to three years after they resumed normal physical activity.

2. Three groups of normal children with corresponding physical characteristics have been studied similarly and used as controls.

3. The following measurements have been made: (a) Lung volumes, (b) maximum breathing capacity, and (c) ventilation, breathing reserve, respiratory gas exchange, and oxygen saturation of arterial blood, under basal conditions, during moderate exercise, during recovery from moderate exercise, and during exhausting exercise.

4. The chief difference between the three children after pneumonectomy and the normal subjects was the constant reduction in their breathing reserves in various states of activity.

5. During exhausting exercise the gas exchange of the children who had undergone pneumonectomy was strikingly similar to that of the normal subjects.

6. The distinction between ventilatory and respiratory function is stressed.

7. The one child whose remaining lung was persistently overdistended showed relatively low vital capacity and maximum breathing capacity. In contrast, the two children whose remaining lungs were of normal size in expiration showed relatively greater vital capacities and maximum breathing capacities.

8. It thus appears that permanent overdistention of the remaining lung following pneumonectomy impairs the mechanics of the chest bellows and, although not always anatomically controllable in children, is not physiologically desirable.

We wish to acknowledge the helpful suggestions of Dr. D. W. Richards, Jr., and Dr. F. B. Berry and the technical assistance of Marianne S. Lester and Irving Yarmush.

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DISCUSSION

DR. EDWARD J. O'BRIEN, Detroit, Mich.—Might it not be well worth while to know, before operation, whether the remaining lung will be able to withstand the sudden strain thrown upon it following pneumonectomy? We had several very interesting papers yesterday afternoon. I should like to call attention especially to Dr. Whitehead's work with which I am most familiar. The open circuit method is used, and definite, known mixtures can be constantly applied to the lung under question, and added strain put upon it. The function of both lungs can be estimated separately before operation, and a reasonably accurate idea of the remaining lung's ability to carry the burden can be obtained. I merely want to suggest that we keep this in mind, for we probably can save some of those patients whose other lung might not be able to withstand the additional strain suddenly thrown upon it following this operation.

Pneumonectomy is usually performed in the older age group where considerable fibrosis and loss of function may exist which cannot be determined by x-ray examination. The lung to be removed, although diseased, may be carrying most of the burden. To test each lung separately is the only way of obtaining this very valuable information.

DR. FRANK B. BERRY, New York, N. Y.—Some years ago we became interested in the subject that Dr. Lester has just presented. Our interest was stimulated by the work of Carter and Longacre at that time, and again last year by Dr. Longacre's further report and the follow-up on these dogs.

We fortunately had, through the kindness of the Commonwealth Fund, a very efficient respiratory laboratory on our service, under the direction of Dr. Cournand and Dr. Riley. With Dr. O'Brien's point in mind, we have been trying to work out, both before and afterward, the respiratory status of these patients.

It is time-consuming and painstaking, but as Dr. O'Brien said a minute ago, it is certainly worth while to know beforehand whether or not such a patient will tolerate a pneumonectomy. And afterward, we have been trying to find out at what point in the distention of the remaining lung will be their maximum point of efficiency and thus prevent and control disabling emphysema.

This, of course, is particularly true in adults. It is now thought that in children, particularly in pneumonectomies in young children where the control of an emphysema, should it develop, would be very difficult (because thoracoplasty in young children is something to be deplored), subsequent plastic operation on the chest wall, even if deemed necessary, should be postponed until the age of 16 if possible.

It would seem, from these very few cases that Dr. Lester has reported, that, in comparison with studies of comparative anatomy, the true lung growth in children is somewhat limited, perhaps more so than it is in certain animals. There is first lung growth, hypertrophy, distention, and then emphysema with which to deal.

In the adults, of course, we have only to deal with the distention and emphysema.

Perhaps as we go along we may be able to find some signs that may indicate what is the maximum distention that has occurred compatible with maximum efficiency, and, by taking proper measures then, prevent a disabling emphysema in the old age group. Such measures, of course, are thoracoplasty, or perhaps oleothorax, which was employed in one instance in a patient who could not possibly have tolerated a subsequent thoracoplasty so it was extremely doubtful if he would tolerate a pneumonectomy.

(Slide) These are two slides of that patient. He is a man of 63 who looked many years older than that. His was as marked a case of emphysema, almost, as I have ever seen. We have not the lateral view here, but the lateral picture showed a chest that looked almost, or at least, three-quarters of the breadth of his p. a. You see the lesion in the left chest.

At that time, his arterial saturation was 91 per cent. He had a residual air of 2.65 liters, and you see his respiration graph on the right, running from right to left.

You can see that he, on maximum inspiration and expiration, has a perfectly good reserve function.

He did not seem to be very much more dyspneic; in fact, he was able to walk about after a few days, and we decided to operate. A complete pneumonectomy was performed. The tumor was in the upper lobe, with suppuration beyond it, and from the surgical standpoint he had a perfectly uneventful convalescence. From his functional standpoint, however, his situation was quite different.

(Slide) His arterial saturation dropped to 85 per cent. He overdistended his right lung; there was almost no motion in his diaphragm; his residual air went up to 2.5 liters, as per his respiratory graph there; and you see he had no reserve air. His residual air at that time was about 70 or 71 per cent of his total, instead of being, as it should have been, around 25 per cent normally or, at least for him, well under 40 per cent.

What fluid there was, was aspirated and substituted with a pneumothorax, with prompt improvement. He regained the excursion of his diaphragm; his oxygen saturation came up to 91 per cent; and his residual air dropped to about 40 per cent.

It was felt at that time that pneumothorax would not be satisfactory as a permanent status for him, and therefore we substituted oleothorax. He had this for seven months. It is noted, however, that, when he comes in to see us, if his diaphragmatic excursion decreases, he becomes dyspneic.

He has just now reached one of those levels, and it is our job, in order to keep him comfortable and at his maximum efficiency, to prevent that lung from overdistending. It was overemphysematous; he had no reserve; he was barely able to carry on his daily life.

It is the aim in all of these studies which we are carrying out before and afterward, at six-month intervals in all of these cases of pneumonectomy, to see when the point comes with the adults, particularly, when it is time to do something, or whether they can be left with the chest filled with serum and fibrin. We have had to do one thoracoplasty in a man of 60, with prompt relief of his symptoms.

Of course, the patients will divide themselves into two groups. It would seem from Dr. Lester's studies, and the few children we have studied, that those who will stabilize the mediastinum will be much more comfortable than those in whom the lungs will distend and spread over into the other chest. At least that spread and strain of the lung should be limited so as not to allow overdistention.

DR. RICHARD L. RILEY.—As Dr. Lester has shown, the performance of these three children after pneumonectomy was remarkably good. The performance of two of them was better than that of the third, however, and I should like to emphasize the reasons for this difference.

Anatomically, the two children whose performance was better had remaining lungs which were less distended than that of the third child whose performance was worse. Surgically, the two children whose performance was better both had postoperative complications which partially stabilized their mediastinums and prevented marked overdistention of the remaining lung. The third child had a remarkably smooth postoperative course. His mediastinum remained mobile, became markedly displaced, and allowed great overdistention of his remaining lung. The performance of this child was poorer.

On the basis of these observations, it is suggested that overdistention of the lung remaining after pneumonectomy is undesirable, and that measures should be considered to prevent this, provided the postoperative complications in themselves do not accomplish this by stabilizing the mediastinum.

As to the types of measures and the time at which they should be undertaken, these are individual problems and must depend upon the age of the patient and upon the anatomic conditions resulting from pneumonectomy.

A STUDY CONCERNING CLINICAL AND ANATOMIC FEATURES OF RE-EXPANDED LUNGS WHICH HAD BEEN COLLAPSED BY PNEUMOTHORAX FOR VARIABLE PERIODS OF TIME

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IT IS not the purpose of this paper to delve into the theoretical considerations of the mode of healing of tuberculous cavities under the influence of collapse therapy. On the contrary, we are interested in the type of healing that takes place and the respiratory capacity with which it leaves the patient. Nor is it intended to give the much desired answer to the question of how long an effective pneumothorax should be maintained. As will be shown later, the question still remains unanswered even when the cases are divided into arbitrary groups according to pathologic findings, without considering the problems of each individual patient. We believe that it is of more practical concern and of greater statistical interest to analyze our experience in a group of patients who have had pneumothorax terminated and who have been followed for one to eight years after re-expansion. Certainly, from such a group of patients, one should be able to derive information concerning the dangers of the treatment from beginning to end, the anatomic and physiologic changes invoked by it, and the nature and duration of the recovered physical state.

The series consisted of 118 patients in whom 162 lungs were collapsed because forty-four of them received bilateral pneumothorax. There were forty-one males and seventy-seven females, and only two of the entire group were colored. The ages of the patients ranged between 13 and 57 years, the average being 25 years. It has been stated by some that in order to obtain the most lasting results with artificial pneumothorax the duration of the collapse should depend upon the size and location of the cavity or cavities, the character of their walls, and the extent and nature of the pericavernous infiltrate. Whether this statement is borne out by our studies will be discussed later, but we feel that the inclusion of the first four tables will give one a better appreciation of the anatomic results obtained after re-expansion. The character of the cavity wall was judged according to the classification of Pinner.[1] It will be noted in Table III that because of the multiplicity of cavities in forty cases (Table I) the total number

From the Hudson County Tuberculosis Hospital, Medical Center, Jersey City.
Read (by title) before the Twenty-Fourth Annual Meeting of the American Association for Thoracic Surgery, Toronto, Canada, June 9, 10, and 11, 1941.

TABLE I

TYPE OF LESION BEFORE INDUCTION OF PNEUMOTHORAX IN 162 LUNGS OF 118 PATIENTS

TYPE OF LESION	NO. OF LUNGS
Multiple cavitation	40
Cavity 2 cm. or less	44
2.5-3.5 cm.	57
3.5-5 cm.	8
5 cm. or more	8
Progressive infiltrative disease	5

TABLE II

CHARACTER OF PERICAVERNOUS INFILTRATE BEFORE INDUCTION OF PNEUMOTHORAX*

CLASS	NO. OF LUNGS
I	51
II	97
III	9

*The difference between 162 lungs under consideration and 157 in Table II is due to five infiltrative lesions.

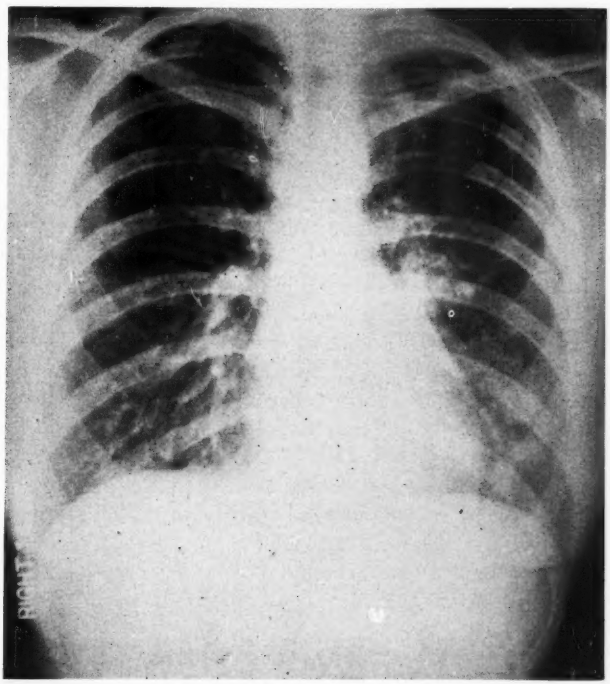

Fig. 1.—Pericavernous infiltrate class I. Left apical cavity with minimal infiltrate about it.

of cavities in the 162 lungs under consideration was 207. Along similar lines we have tried to indicate the density of the pericavernous infiltrate by grouping it into three classes. As indicated in Figs. 1, 2, 3, and 4, a pericavernous infiltrate of the first degree is one represented by nodules or small densities scattered about the cavity with ample intervening normal lung tissue; in class II, the infiltrate is more confluent; while in the third class belong consolidations of a lobe or of an entire lung or the very dense fibrotic patches which completely encircle the cavity wall.

TABLE III

CHARACTER OF CAVITY WALL ACCORDING TO PINNER'S CLASSIFICATION

CAVITY WALL	NO. OF CAVITIES
Type I	64
Type II	134
Type III	9

TABLE IV

LOCATION OF CAVITIES

ZONE IN LUNG	NO. OF CASES
Outer	48
Mid	68
Inner	16
Apex	19
All zones	6

Now a good deal has been said about the complications of pneumothorax, and it has even been suggested that thoracoplasty may be preferable in suitable cases because of the possible complications when one has to carry a pneumothorax for several years. It is, therefore, of interest to see what complications were encountered and what role their presence played in the ultimate outcome (Table V). Only 10 per cent of the pleural cavities entered were free from adhesions; in the rest in spite of adhesions an effective collapse was obtained without the addition of a supplementary procedure except in four cases. This is not to be construed that pneumonolysis or supplementary phrenic interruption was rarely indicated. As a matter of fact, in retrospect we realize that in many instances an effective collapse could have been obtained sooner if these procedures had been practiced more often.

TABLE V

COMPLICATIONS OF PNEUMOTHORAX

COMPLICATION	NO. OF INSTANCES
Effusion (nonempyematous)	109
Empyema	5
Superimposed traumatic pneumothorax	4
Adhesions	143
Deviation of mediastinum	4
Mediastinal herniation	1
Atelectasis	14

If one takes into account pleural effusions in the costophrenic sinus, then not a single patient escaped this complication at some time during his pneumothorax career. However, if only the more extensive effusions are considered, our experience shows a 70 per cent incidence. In five patients the effusions became empyematous. Other complications encountered consisted of superimposed "spontaneous" pneumothorax four times, mediastinal deviations and/or herniation five times. and atelectasis of a lobe or an entire lung fourteen times.

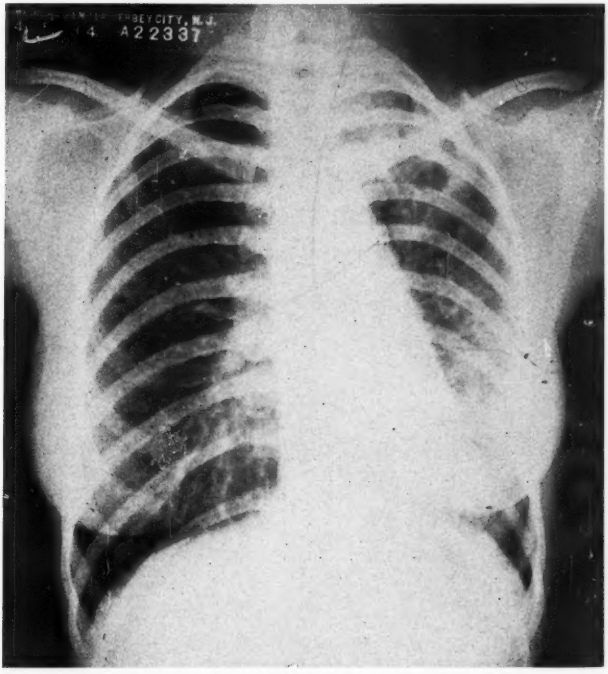

Fig. 2.—Pericavernous infiltrate class II. Cavity in the mid zone in the left first interspace with a moderate degree of confluent infiltrate about it.

The mere occurrence of these complications is not to be feared if one can demonstrate that ultimately the incidence of their control is such that their crippling or fatal effects are infrequent. The empyemas were brought under control by repeated aspirations in two instances and by replacement oleothorax in the remainder. In the 109 instances of nonempyematous effusions spontaneous resorption resulted in all but two in which a replacement oleothorax was necessary. In the process of resorption the pneumothorax space could not be maintained as long as was originally planned in seventeen instances. The superimposed "spontaneous" pneumothoraces were traumatic in all of the four patients and were controlled either by repeated aspirations of air

or by underwater intercostal drainage. Mediastinal herniations or marked deviations were controlled either by letting up on the pneumothorax or by fixation of the mediastinum. As for the atelectases which followed pneumothorax, the ultimate outcome can be evaluated in twelve of the fourteen cases in which re-expansion has taken place. Reaeration of the lobe or lung occurred seven times; residual shrunken lobe or lung occurred four times; atelectasis remained after re-expansion in one instance.

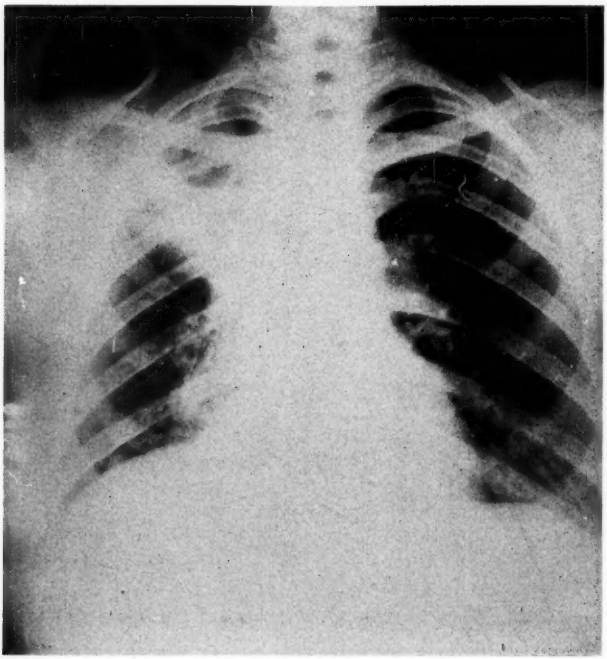

Fig. 3.—Pericavernous infiltrate class III. Large cavity in the right upper lobe which presents a tuberculous pneumonia.

Another controversial point upon which our study sheds light is the fate of the contralateral lung (Table VI). In this group of 118 cases, twelve presented on admission large cavities in both lungs and were, therefore, bilateral pneumothorax problems at the very start. In thirty-one the lesions were essentially unilateral and, of these, two developed disease in the opposite lung three and four years after re-expansion, respectively. The remaining seventy-five presented minimal or moderately advanced infiltration in the better lung and in not a few the infiltrate was accompanied by cavitation 2 cm. or less in diameter. The disease progressed in thirty-two of these so that they required collapse therapy, while eight remained stationary and thirty-five improved. It is obvious, therefore, that with the collapse of unilateral

disease the chances for a lesion to occur in the contralateral lung are very small, and that, of those in whom the disease is bilateral, at least one-third show improvement in the opposite lung sufficient to convert the problem to an essentially unilateral one.

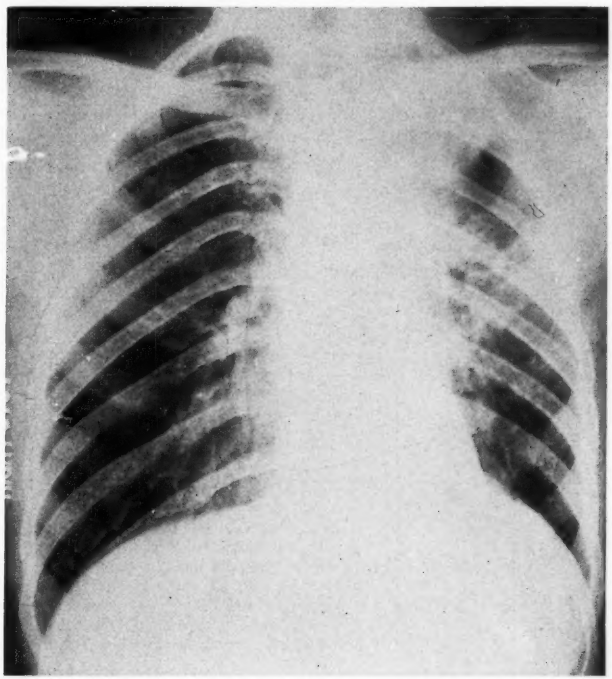

Fig. 4.—Pericavernous infiltrate class III. Deviation of the trachea to the left due to a fibrotic infiltrate of the left upper lobe within which there is a cavity.

In the beginning of our pneumothorax period we arbitrarily agreed on a minimum maintenance period for an effective pneumothorax in cavitary lesions of various sizes. Thus, in the small cavity group a minimum of eighteen and preferably twenty-four months was to elapse from the time an effective collapse was obtained to full re-expansion of the lung. Cavities 2.5 to 3.5 cm. in diameter would be given 2.5 to 3 years; cavities 3.5 to 5 cm., 3.5 to 4 years; and cavities over 5 cm. in diameter, 5 years or longer. While this is the goal for which we aimed we fell far short of it in twenty-six instances wherein either adhesions or effusions brought about re-expansion of the lung on an average of sixteen months after an effective pneumothorax had been established and after as short an interval as five months (Table VII). Even in the remaining 126 re-expanded lungs which were considered voluntarily abandoned the minimum was maintained for the small cavity group in all instances but only in the vast majority of cases in

the larger cavity group. A study of Table VIII indicates that, while an equal number of recurrences took place in the voluntary and involuntary re-expanded lungs, the proportionate number of recurrences is almost five times as great in the latter group as in the former. This confirms the general observation that the chances for recurrence are vastly greater in those in whom an effective collapse cannot be maintained for an "adequate period of time." But what constitutes an adequate period cannot, as was indicated in the introductory remarks to this paper, be stated definitely when it is considered that recurrence has not taken place in the remainder of the involuntary re-expanded cases or in the voluntary re-expanded group in which the minimum period of collapse was strictly maintained.

TABLE VI

FATE OF THE DISEASE IN THE "BETTER LUNG"

EXTENT OF DISEASE	NO. OF CASES	WHAT HAPPENED TO THE "BETTER LUNG"
Essentially unilateral disease	31	1 patient developed a cavity 4 years after re-expansion and is now receiving effective pneumothorax. 1 patient developed a cavity 3 years after re-expansion and died after an apicolysis operation. 29 cases showed no change.
Bilateral disease	87	12 cases showed bilateral collapse problem initially. 10 of these patients received bilateral pneumothorax and 2 received pneumothorax on one side and thoracoplasty on the other. In 32 cases the disease in the better lung progressed. 30 of these received bilateral pneumothorax and 2 received pneumothorax on one side and thoracoplasty on the other. In 8 cases the lesion in the better lung remained unchanged. In 35 cases the better lung improved.

TABLE VII

PERIOD OF EFFECTIVE COLLAPSE IN 152 RE-EXPANDED LUNGS*

TYPE OF PNEUMOTHORAX	VOLUNTARY RE-EXPANSION		INVOLUNTARY RE-EXPANSION	
	(61 Lungs)		*(13 Lungs)*	
Unilateral	Minimum	2 mo.	Minimum	8 mo.
	Maximum	80 mo.	Maximum	26 mo.
	Average	41.9 mo.	Average	15.8 mo.
	(65 Lungs)		*(13 Lungs)*	
Bilateral	Minimum	20 mo.	Minimum	5 mo.
	Maximum	64 mo.	Maximum	32 mo.
	Average	45.2 mo.	Average	17 mo.

*The difference between 162 lungs under consideration and 152 in the table is due to the fact that ten lungs are still under collapse.

After dividing the patients according to the size and location of the cavities, character of their walls and the degree of pericavernous infiltrate as indicated in Tables I, II, III, and IV, and correlating these factors with the resultant healed lesions in the inflated lung (Table IX) and their capacity to recur (Table VIII), we received no clue to

the problem except for the general statement that, regardless of the type of lesion, recurrences are much more prevalent if an effective pneumothorax is maintained for an average of less than eighteen months than if it is continued longer. Beyond this, it seems as though it is a matter of chance as to whether reactivation will take place after re-expansion. Nevertheless, we have the impression that the results obtained were not in a small part due to the fact that we strove in each case, depending upon pathologic findings, to meet the minimum period of collapse set out at the beginning of treatment. Until such time as when either experimental or clinical work sheds more light on this point we would urge individualization of treatment rather than the adherence to the arbitrary statement[2] that eighteen months to two years is a sufficient period of collapse.

TABLE VIII

RECURRENCE OF DISEASE AFTER RE-EXPANSION

TYPE OF RE-EXPANSION	INITIAL LESION	MONTHS OF EFFECTIVE COLLAPSE	INTERVAL BETWEEN RE-EXPANSION AND RELAPSE	PRESENT STATUS
Voluntary (126 lungs) Recurrence in 6 lungs	Multiple small cavities	33	3 yr.	Cavity closed spontaneously on bed rest
	3 cm.	54	3 yr.	Cavity closed spontaneously on bed rest
	2.5 cm.	34	1 yr.	Recollapsed—Pneumothorax now effective
	Progressive minimal infiltrate	33	8 mo.	Progressive clearing on bed rest
	3.5 cm.	50	1 yr.	Closed with phrenic interruption
	2 cm.	21	1 yr.	Responding to bed rest
Involuntary (26 lungs) Recurrence in 5 lungs	2 cm.	7	3 yr.	Cavity still open
	2.5 cm.	5	5 mo.	Cavity closed with phrenic interruption
	2 cm.	12	7 mo.	Sputum positive. Small residue of cavity present. To undergo surgery
	Multiple small cavities	11	20 mo.	Spontaneous closure on bed rest
	Multiple small cavities	12	On re-expansion	Dead (progressive disease)
	*2.5 cm.	8	On re-expansion	Cavity still present

*This is the same case as the second one under the voluntary re-expansion group—a bilateral pneumothorax.

Equally interesting and of practical importance are the anatomic changes in the lesions which take place with treatment as revealed on re-expansion (Table IX). It should be said that, in comparing the

TABLE IX

TYPE OF LESION ON RE-EXPANSION*

RESIDUAL LESION	NO. OF LUNGS
Fibrotic nodules	93
Stringy infiltrate	12
Fibrocalcific infiltrate	35
Dense fibrotic patches	3
Shrunken lobe	6
Atelectasis	3

*The difference between 162 lungs under consideration and 152 in the table is due to ten lungs still under collapse.

extent of the residual lesion in the reinflated lung with that present before pneumothorax, one was impressed with the degree of resorption that had taken place. In other words, the infiltrate left after healing was surprisingly less in extent than that found prior to collapse in practically all instances except in a few cases in which the original lesion or the pericavernous infiltrate was very extensive. In the latter, fibrosis as viewed in the x-ray film was appreciable. Except for the recurrences, the lesions in the re-expanded lungs have remained unchanged to date except in nine instances. In the latter, the residual fibrotic infiltrate either became calcified or showed further clearing as long as forty-eight months after re-expansion. The frequency and extent of changes in the associated structures, such as the pleura, mediastinum, and the diaphragm, are shown in Table X. In most instances these changes were of minimal or moderate extent and in no case resulted in respiratory embarrassment. In this connection it is interesting to note that the pathologic changes enumerated have been observed at post-mortem examination in 134 thoracoplasty cases as reported by Auerbach[3] before the American Association for Thoracic Surgery in Toronto, June, 1941. How much the respiratory reserve is reduced as a result of the various combinations of changes encountered after re-expansion is the study we are now undertaking and which will make up a future report. Although subclinical reduced respiratory reserve is found in re-expanded cases,[4-6] our experience indicates that, if re-expansion is properly carried out, the number of patients left with evident dyspnea is, indeed, very small.

TABLE X

CHANGES IN ASSOCIATED STRUCTURES ON RE-EXPANSION

STRUCTURAL CHANGE	NO. OF INSTANCES
Thickened pleura	68
Deviation of mediastinum	20
Elevation of diaphragm	6

That re-expansion can take place in the vast majority of instances without resorting to supplementary surgery is attested by the fact that in only three cases was phrenic interruption necessary in order to bring about the complete obliteration of the pleural space.

At this point, we should like to reiterate and emphasize several features with respect to the process of re-expansion mentioned by other authors. When one decides to abandon a pneumothorax after an adequate period of effective collapse, the refill intervals should be shortened. When intrapleural pressures are taken more frequently, high negative pressures with their resultant mediastinal deviations are avoided. What is more, the negative pressure at each sitting can be so adjusted as to leave it just a few points higher than normal; thus a slow and steady traction on the lung is established. Clinically this method of re-expansion is particularly desirable in that it gives the physician a fair trial period in which to observe by clinical and laboratory studies the reaction of the residual disease to reinflation. By the prevention of marked deviation of the mediastinum, points of fixation between the visceral and parietal pleura are avoided, and thus recollapse of the lung at any point prior to full re-expansion can usually be established if reactivation occurs. In our experience full reinflation of the lung under these conditions takes from three to nine months.

Finally, we offer in Table XI the present status of the 118 patients in this report. It might be of interest to note that the majority of those working or able to work at the present time did so during most of their pneumothorax career.

TABLE XI

PRESENT STATUS OF PATIENTS (1 TO 8 YEARS AFTER RE-EXPANSION)

STATUS	NO. OF PATIENTS
Working or able to work	90
Ambulant	20
Under treatment	5
Dead	3

SUMMARY

1. The study concerns 152 re-expanded lungs in 118 patients.

2. The period of observation since reinflation varied from one to eight years.

3. The following clinical and anatomic features are considered.

a. The disease in the lungs prior to pneumothorax—i.e., size and location of the cavities, the character of their walls, and the extent and density of the pericavernous infiltrate.

b. The complications encountered from beginning to end of treatment, their management, and the final outcome.

c. The effect of collapse on the "better" lung.

d. The duration of effective collapse and its relation to recurrence of the disease.

e. The residual changes in the lungs and their associated structures after re-expansion and their effects on respiratory reserve.

f. The capacity of a lung to reinflate after collapse and a method of re-expansion that minimizes distortion of mediastinal structures.

g. The present clinical status of the patients under consideration.

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RESPIRATORY OBSTRUCTION FROM BRONCHIOLAR CONSTRICTION DURING CYCLOPROPANE ANESTHESIA

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DURING the course of clinical anesthesia with cyclopropane there has been observed infrequently what appeared to be lower respiratory tract obstruction. Such obstruction often demonstrates itself by a type of respiration strongly suggestive of that seen during an asthmatic attack. It is usually accompanied by a substantial cyanosis, and with some patients this latter sign predominates. This clinical entity has been referred to as bronchospasm, although it has more often been mistaken for laryngospasm due to the inspiratory difficulties of the patient.

The condition has been observed in patients whose glottis was being maintained patent with an endotracheal airway. With obstruction in the upper respiratory tract and particularly at the vocal cords eliminated, labored respirations coupled with cyanosis or other evidences of oxygen want in the presence of high oxygen dilutions in the inspired atmosphere justify the conclusion that obstruction is in the lower respiratory tract. Moreover, it seems evident from the nature of the obstruction observed in these patients and the attending signs that some degree of spasm of the bronchial system below the main division of the primary bronchi exists. Examples of this phenomenon are most often seen in patients with history of allergic sensitivity, bronchial asthma, or emphysema. Reference to this reaction has appeared in the literature. Bonham[1] described several patients exhibiting these phenomena during cyclopropane anesthesia, and all of his patients had a previous history of allergic sensitivity either in the form of hay fever or asthma. Bonham further observed good results in some cases by adding helium, and in others which were more severe a shift to lighter gases such as ethylene caused immediate relief. There are reports of an opposite effect. Schotz and Meyer[2] described a nonsurgical patient whose asthma seemed to be clinically improved with cyclopropane anesthesia. This patient, when given cyclopropane during a severe asthmatic attack, coughed up large amounts of thick sputum and was promptly relieved. The possibility that an existing atelectasis complicating the asthma was relieved by coughing was not entirely eliminated. One of our records is that of a patient with severe asthma, who, after a liberal amount of morphine, continued in her attack. Despite the

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asthma an indicated cholecystectomy was completed during cyclopropane anesthesia. Nothing in the uneventful postoperative convalescence suggested that the patient suffered from asthma.

The impression that the effect of cyclopropane upon the bronchial nervous mechanism is essentially that of constriction for some patients is strengthened by a number of clinical observations and established in one case by direct observation during bronchoscopic examination. The following case reports are illustrative.

CASE REPORTS

CASE 1.—A white male, aged 60 years, with emphysema and generalized arteriosclerosis was given morphine sulfate 0.008 Gm. (⅛ gr.) and scopolamine hydrochloride 0.0003 Gm. (1/200 gr.) at 8:00 A.M. preparatory to anesthesia and open reduction of fracture of the tibia. At 9:30 A.M. the patient was not depressed. There was no cyanosis; the breathing was normal with a respiratory rate of 20 per minute. The blood pressure was 130/70, and the pulse rate, 74 per minute. Cyclopropane anesthesia was uneventfully induced using the carbon dioxide absorption technique. After seven minutes of anesthesia and immediately before surgery the pulse rate increased to 90 and the patient was noted to be slightly cyanotic. There were inspiratory and expiratory sibilant râles; the expiratory were more prominent. The carbon dioxide absorbing unit was changed, and more oxygen was added to the anesthetic mixture. The condition became progressively worse. Atropine sulfate 0.0002 Gm. (1/300 gr.) was given intravenously. The immediate effect was not pronounced and an identical dose was given five minutes later. Within the next five minutes the cyanosis cleared and all râles disappeared. Throughout the next hour the degree of cyclopropane narcosis was varied from first to third plane repeatedly but no abnormal respiratory signs were noted.

CASE 2.—A white female, aged 70 years, with emphysema, arteriosclerosis and hypertension, was scheduled for excision of umbilical tumor. At 9:30 A.M. morphine sulfate 0.0054 Gm. (gr. 1/12) and scopolamine hydrochloride 0.0003 Gm. (gr. 1/200) were given subcutaneously. Before anesthesia was induced at 11:20 A.M., no cyanosis or disturbance in breathing was noted. After nine minutes of cyclopropane anesthesia, cyanosis and difficult breathing were evident. These signs increased, and auscultation of the chest revealed many sibilant râles, wheezes, and squeaks. An endotracheal airway was put in place but had no effect upon the respiratory disturbance. After twenty-two minutes of anesthesia ether was substituted for cyclopropane. The cyanosis, labored breathing, and the signs in the chest were eliminated promptly.

CASE 3.—A white female, aged 40 years, with a long history of chronic cough and occasional asthmatic attacks, was anesthetized to permit reduction of an incarcerated femoral hernia. At 8:04 A.M. morphine sulfate 0.011 Gm. (gr. 1/6) and scopolamine hydrochloride 0.0004 Gm. (gr. 1/150) were given subcutaneously. At 8:40 A.M. cyclopropane was administered by the carbon dioxide absorption technique. The induction was slightly prolonged with cyanosis and difficult breathing. An oral endotracheal airway was put in place fifteen minutes after anesthesia was started, but an obstructed type of breathing persisted. After forty minutes of cyclopropane administration 48 mg. of ephedrine sulfate were given intravenously. This was followed by complete relief of cyanosis and obstructed respirations. Postoperatively, the patient had repeated asthmatic attacks during the period in which she was under hospital observation.

CASE 4.—A white male, aged 60 years, had generalized arteriosclerosis, arteriosclerotic heart disease, moderate diabetes mellitus adequately controlled, and car-

cinoma of the right lung. Preanesthetic medication with morphine sulfate 0.008 Gm. (gr. ⅛) and scopolamine hydrochloride 0.0004 Gm. (gr. 1/150) was given subcutaneously at 1:30 P.M. Before anesthesia was induced at 3:10 P.M. there was no cyanosis, although the patient coughed some. Cyclopropane was given by the carbon dioxide absorption technique. The induction was uneventful, and after seven minutes an oral endotracheal airway was put in place. Twelve minutes after the start of anesthesia cyanosis was noted and there was marked difficulty in breathing. The signs rapidly increased, on which account ether was substituted for cyclopropane. Considerable relief of the symptoms of lower bronchial obstruction followed. Atropine sulfate 0.0006 Gm. (gr. 1/100) was then given intravenously, after which respirations were similar to those noted preoperatively, and pneumonectomy was completed.

CASE 5.—A patient who frequently suffered from asthma was scheduled for bronchoscopic examination. At the patient's request because of fear of the procedure, inhalation anesthesia was employed. After the patient was uneventfully anesthetized with cyclopropane, the bronchoscope was put in place. The bronchoscopist observed marked constriction of the bronchi.[3] This was relieved by changing the anesthetic agent to ether. Later as the ether anesthesia lightened, cyclopropane was given again, and again the bronchi were seen by direct vision to constrict.

DISCUSSION

The clinical observations presented are strongly indicative of specific action of cyclopropane on the bronchial tissues of certain patients. To recall the physiology and pharmacology concerned, the work of Macklin[4] is cited. He demonstrated that the vagus is the major bronchomotor nerve, resulting in contraction of the bronchi, and suggested that the vagus may also carry some dilator fibers as well. Francis,[5] by lipoidal studies of the tracheobronchial tree, essentially verified these findings. Dixon,[6] in a study of the production of bronchial spasm, verified the fact that the bronchoconstrictor fibers are carried by the vagus. The apparent dilator effect of vagal stimulation was shown by Dixon and Ransom[7] to be due to sympathetic nerves which are intimately associated with the vagus. The exact pathways of the dilator fibers are not as well outlined as are the constrictor fibers, but most of the evidence indicates that this is a sympathetic function. Tainter and his coworkers[8, 9] reported laboratory experiments with a series of sympathomimetic compounds having a bronchodilator action.

Dixon[6] found drugs which act by stimulation of the parasympathetic, such as pilocarpine or eserine, result in constriction of the bronchi by peripheral stimulation of vagal endings. Ether acting as a sympathetic stimulant is known for its bronchodilator effect in asthmatic patients.[10] Sollman and Gilbert[11] recently utilized microscopic observation of thin sections of fresh lungs to show that bronchiolar constriction was markedly increased by parasympathetic stimulants (mecholyl, pilocarpine, and physostigmine) and by histamine, while atropine and adrenalin dilated the normal bronchioles and antagonized both parasympathetic constrictors and histamine. Chloroform and ether produced slight constriction followed by dilatation.

There is now accumulated a number of laboratory studies with cyclopropane which indicate that its action is essentially parasympathomimetic. This possibility was mentioned by Seevers and his coworkers,[12] who discussed the cardiac effects of cyclopropane. They felt that it was possible that certain of the cardiac arrhythmias seen during cyclopropane anesthesia were due to increased vagal tone and added the observation that these phenomena disappeared after atropine. Burstein[13] adduced further evidence in a study of intestinal activity during cyclopropane anesthesia. Adriani and Rovenstine[14] recently submitted a study in vitro on the action of cyclopropane upon reptilian and amphibian heart muscle which favors the belief that this drug has an acetylcholine-like action. The same authors with Martin[15] have utilized the method of Tashiro and his co-workers[16] for the assay of acetylcholine by the response of chromodacryorrhea in the eserinized albino rat. A positive response was obtained in these eserinized animals treated with cyclopropane. Recently studies on the bronchiolar reactions of many anesthetic agents by direct observation of perfused, excised lung tissues have been completed when a modification of the Sollman method was used.[17] Cyclopropane was shown to produce a constrictor effect on bronchial musculature which could be prevented by previously adding atropine and could be relieved when atropine was added subsequently. Robbins[18] presented laboratory evidence to indicate that changes in the heart rate and rhythm brought about by cyclopropane anesthesia are due to the action of this agent upon and through the vagal system. He described studies which essentially demonstrate the effect of cyclopropane upon the parasympathetic division of the autonomic nervous system. Such conclusions were not clearly drawn and the interpretation is confused by regarding cyclopropane and ether as having the same pharmocologic action. Ether[19, 20] acts by stimulating the sympathetic system while Robbins' work indicates a parasympathetic stimulating action of cyclopropane. He used dogs with the sympathetic innervation of the heart removed. Cyclopropane anesthesia caused a reduction of the cardiac rate from 110 to 63, whereas with ether the rate was increased to 113. Then the vagi were sectioned, with an increase of the heart rate to 131 in the awakened animal. Subsequent anesthesia with cyclopropane caused essentially no reduction in heart rate, nor did anesthetization with ether cause any evident change. It was suggested that these effects were partially if not largely due to action of morphine, although pharmacologically it would seem to be evidence to support the stimulating effect of cyclopropane upon the vagi.

The clinical cases cited in this report may be interpreted to support the laboratory evidence. In Case 1 atropine antagonized vagal stimulation and relieved obvious bronchial obstruction. Ether, by stimulating the sympathetics, gave a similar result in Cases 2 and 4. In Case

3 ephedrine was an effective bronchodilator in the presence of pharmacologically induced constriction. The direct observation with a bronchoscope in Case 5 is especially significant.

SUMMARY

A number of clinical case reports have been cited to substantiate the impression that cyclopropane may cause bronchiolar reactions in certain patients. The clinical findings are briefly the signs of bronchial constriction in the anesthetized patient, that is, labored breathing often coupled with varying degree of cyanosis, and often associated with marked respiratory wheezing throughout the chest. The picture may be confused with that of upper respiratory obstruction, particularly laryngospasm, but, when this latter may be eliminated as a possibility by the insertion of an endotracheal airway, the diagnosis of lower bronchial obstruction should be made. The reaction is most frequently observed in patients with a history of allergic sensitivity, such as asthma, and certain forms of accompanying emphysema. For these the prophylactic use of liberal amounts of atropine may be useful. When the condition is encountered during cyclopropane anesthesia, several therapeutic measures are available. In the cases reported, those selected were treated satisfactorily by different means. If ether is not contraindicated, a shift to this agent will effect an immediate result. Atropine may be given intravenously; ephedrine may be used; and helium has been found useful.

The mechanism for this reaction is reviewed, and, since it is essentially one of vagal stimulation and follows the administration of parasympathetic stimulants, it is suggested that cyclopropane has such an effect in certain human beings. Experimental investigations that support the clinical observations that cyclopropane has essentially an action of parasympathetic stimulation are reviewed.

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